Engineering Research Series
no. 14

Texas. University of. Bureau of Engineering Research

TA
1
T45
no. 14
ENGIN STORAGE

University of Texas Bulletin

No. 1771: December 20, 1917

Tests of Concrete Aggregates Used in Texas

~~Physical &~~
~~Applied Sci.~~
~~Serials~~
Engineering

By

J. P. Nash
Testing Engineer

BUREAU OF ECONOMIC GEOLOGY AND TECHNOLOGY
J. A. Udden, Director
DIVISION OF ENGINEERING
F. E. Giesecke, Head of the Division

LIBRARY
JUN 1 1923
UNIVERSITY OF TORONTO

PUBLISHED BY
THE UNIVERSITY OF TEXAS
AUSTIN

Publications of the University of Texas

Publications Committee:

F. W. GRAFF	R. H. GRIFFITH
J. M. BRYANT	J. L. HENDERSON
D. B. CASTEEL	I. P. HILDEBRAND
FREDERIC DUNCALF	E. J. MATHEWS

The University publishes bulletins six times a month, so numbered that the first two digits of the number show the year of issue, the last two the position in the yearly series. (For example, No. 1701 is the first bulletin of the year 1917.) These comprise the official publications of the University, publications on humanistic and scientific subjects, bulletins prepared by the Department of Extension and by the Bureau of Municipal Research and Reference, and other bulletins of general educational interest. With the exception of special numbers, any bulletin will be sent to a citizen of Texas free on request. All communications about University publications should be addressed to the Chairman of the Publications Committee, University of Texas, Austin.

B293-818-15h

University of Texas Bulletin

No. 1771: December 20, 1917

Tests of Concrete Aggregates Used in Texas

By

J. P. Nash
Testing Engineer

BUREAU OF ECONOMIC GEOLOGY AND TECHNOLOGY
J. A. Udden, Director
DIVISION OF ENGINEERING
F. E. Giesecke, Head of the Division

PUBLISHED BY THE UNIVERSITY SIX TIMES A MONTH, AND ENTERED AS
SECOND-CLASS MATTER AT THE POSTOFFICE AT AUSTIN, TEXAS,
UNDER THE ACT OF AUGUST 24, 1912

The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

TESTS OF CONCRETE AGGREGATES IN TEXAS

Introduction.

The question as to the value of materials produced in the State for use in concrete is one of importance. Concrete is used extensively in all branches of construction, and the demand for it is rapidly increasing. A few years ago concrete roads in Texas were a new thing, but now they are well known to the average person. In this state, also, the use of concrete in large building construction is surpassing steel and even timber construction in volume.

In order to obtain some definite information regarding the strength of concrete in which Texas aggregates have been used, these tests were made. The results of the tests are not given with the idea of presenting any new data upon the properties of concrete aggregate, but should they help the engineer and contractor in erecting safe and economical structures, or the highway engineer in designing the best of concrete roads, they will have fulfilled their mission.

Further, the tests should be of value as a base for future work of this kind, that is, in studying methods of improving the quality of the concrete, or possibly in deciding the question of using local materials in preference to shipping the aggregate from a distance.

If concrete were sold according to the strength developed rather than according to arbitrary specifications, there would be much more study given to the details of the materials and methods used in making concrete.

An object also sought in the tests is to determine as far as possible the usefulness of the aggregate for concrete road construction. This type of road construction is rapidly finding favor with road builders on account of its endurance when the road is properly built and correct materials used. At the same time, concrete may have considerable resistance to tension and compression, and yet resist the wearing action of traffic but little. This is important with a concrete road, as the life of this type of road is dependent in a great measure upon its resistance to wear.

Many factors enter into the production of concrete that affect its strength besides the character of the materials. The proportions and grading of the aggregates, the method and time of mixing, the consistency, the method of placing and tamping, method of curing and the age of the concrete, all affect the strength. Besides these variables, the physical agencies of temperature, atmospheric moisture, and wind, affect the concrete while setting, and produce an inferior concrete when the conditions are not correct.

In the laboratory, the variables can be limited to a minimum and those still existing can be recorded so that a result may be duplicated with the same materials. It is practically impossible to obtain the same results in the field as in the laboratory, but by using methods applicable to field work in the laboratory, a closer co-ordination of results can be obtained. In any event, the variables in the strength of the concrete caused by differences in the materials themselves will be the same whether the concrete was made in the laboratory or in the field.

While good cement and a sufficient amount are essential to produce a given strength concrete, it is very often possible by the use of proper aggregates, correctly handled, to obtain the same strength concrete with much smaller amounts of cement.

The results of these tests give the strength of concrete made from various aggregates under certain definite stated conditions. When these conditions change, the strength of the concrete will also change to a certain degree, even though the cement content remains the same. When this variation in strength is known for a few of these conditions, it may be estimated for many others. The conditions used in these tests include the variation of the proportions of coarse and fine aggregate, the cement remaining the same, varying the proportions of cement, changing the character or grading of the sand, and in one or two instances changing the size of coarse aggregate. As many of these variations in the aggregates were made as materials permitted.

The Aggregates

The aggregates tested were supplied by producers in Texas and two outside the State. The latter two find a market for their material within the State. These materials were sent to the laboratory in response to letters sent to all the known producers in the State. It is believed that the samples tested represent fairly well the various localities, and also a large proportion of the tonnage produced in the State. This method of obtaining samples was adopted not through choice, but because of the limited funds which precluded the use of other methods. It is believed that the samples are fairly representative. At any rate, enough data is given to enable one to identify the material of any of the deposits.

The amount of material requested was not less than 500 pounds, but few samples contained this amount, so that the tests were limited by the amount of materials received. The following is a list of the producers whose products are represented in these tests:

Austin Sand and Gravel Co., Austin, Travis Co	Pit run gravel
Birmingham Slag Co., Birmingham, Ala	Crushed slag
Chico Crushed Stone Co., Ranger, Eastland Co	Crushed limestone
Comal Rock Co., New Braunfels, Comal Co	Crushed limestone
Dittlinger Lime Co., New Braunfels, Comal Co	Crushed limestone
A. C. Fox Stone Quarry Co., Lueders, Jones Co	Crushed limestone
Horton & Horton, Houston, Harris Co	Gravel
McLean Gravel and Sand Co., Carrollton, Dallas Co	Gravel and sand
Mineral Wells Crushed Stone Co., Mineral Wells, Palo Pinto Co	Crushed limestone
Risley Bros., Jacksboro, Jack Co	Crushed limestone
J. Fred Smith Sand and Gravel Co., Dallas, Dallas Co	Pit run gravel
Texas Sand Co., Texarkana, Bowie Co	Gravel and sand
Texas Trap Rock Co., San Antonio, Bexar Co	Crushed trap rock
J. W. Thompson, New Orleans, La	Sand and gravel
Urbana Gravel Co., Houston, Harris Co	Pit run gravel
Wagner Sand Co., San Antonio, Bexar Co	Sand
White Rock Gravel and Sand Co., Waco, McLennan Co	Gravel and sand

A number of these producers sent several of their products, while others limited the samples to one.

Tests Made

The variety and number of these tests made on an aggregate were dependent upon the nature and amount of material received. With all the aggregates, the properties identifying the material were ascertained. These include the weight of the dry aggregate per cubic foot both loose and packed, and the specific gravity. From these two values the voids were calculated. A mechanical analysis served to indicate the grading of the aggregates, and the characteristics of the materials were noted. Specifications embodying these data should assure an architect or engineer of obtaining similar aggregates. The purpose of this is to make it possible to write a specification calling for similar material so that it will be only necessary to identify the material without further tests.

The aggregates were tested by incorporating them in concrete and testing the various properties of the resultant concrete. In any event, all coarse aggregates were mixed in definite proportions with sand and cement and tested in compression.

Unquestionably the big advantage of concrete as a building material is the ease with which it lends itself to the use of local materials. Some materials are more suited for this purpose than others, but in many cases where poorer materials are used, the strength of the concrete can be increased by the use of more cement to equal concrete made of better material. This is a matter of economics and shows the fallacy of specifying an arbitrary mix such as a 1:2:4 for all materials. No premium is placed on superior aggregates.

Concrete specimens were made first using definite proportions such as 1:2:4 and 1:3:6, and the remaining material tested from various points of view. In some tests, the proportions were varied in order that it might be determined whether or not better concrete could be secured by increasing or decreasing the proportion of sand to coarse aggregates. Where samples permitted, different sands were used with the coarse aggregate so that the results might be of value when similar local sands were used. In several cases also, the aggregate was altered so as to meet requirements of commercial work. This alteration was limited, however, to removing all materials above a certain size, and observing the effect on the resulting concrete. As many compression tests as material permitted were made after the concrete had aged for six months, the aging of the specimens being conducted as near to practical methods as possible.

To test it as a concrete road aggregate, the material was incorporated into concrete specimens, and tested for its resistance to abrasion and also its tensile strength. These tests were made only on crushed stone, slag, and screened gravel.

Pit run gravels were tested for their value as concrete aggregates by testing compression specimens made by mixing the gravels with cement in definite proportions as for instance a 1:4 or 1:6 mix. In many localities in this State, the use of pit run gravel is permitted, invariably under the impression that it obtains as good concrete as does screened and remixed gravel. To obtain a comparison between concrete made from screened gravel and that made using the pit run gravel, the latter was screened through a ¼″ sieve, remixed in definite proportions, with cement, and tested upon aging.

The value of screening pit run gravel and remixing the sand and screened gravel in definite proportions to obtain a more economical concrete is well illustrated in the tests of the pit run gravel of the Austin Sand & Gravel Co. For instance, it has been found that a 1:6 mix with pit run gravel will require as much as 1 sack more cement per cubic yard of set concrete than if the material had been screened and remixed in the proportions of 1:3:6, and still gives less strength than the latter.

In considering the pit run gravels, specimens were made of this material and it was then screened through the ¼″ mesh sieve. The sand and screened gravel were then considered separately and examined as such.

With the sand and screenings the same identification tests were made as on the pit run gravel. Besides these, the sand was tested for its mortar-making qualities, by comparing tensile and compression briquettes made with the sand or screenings in question with the same type specimens made with the standard Ottowa sand. In some cases an attempt was made to determine the usefulness of the fine aggregate in question when used in concrete, by testing it with different types of coarse aggregates. It must be kept in mind, however, that this test only shows what strength concrete may be expected from the sand when the same kind of coarse aggregate is used.

In all tests made, practical applications of the results were kept in mind so that the results obtained should apply to the field work. The methods of mixing, placing, and curing, are a compromise of strict laboratory methods and field methods. It is necessary in the testing of concrete that the number of variables be a minimum for the results to be of any value, and this can seldom be done in field work.

Materials and Methods

The cement was a blend of three Texas cements thoroughly mixed. It was stored in a paper-lined box, away from dampness, and was used completely in a few months. This necessitated the refilling of the bin. The second batch of cement was composed of four brands of Texas cements. The bin was filled a third time with the four-brand blend of cements which passed the tests of the American Society for Testing Materials. Some difference, however, was found in the tests of the cement as follows:

1:3 Tensile Strength Test

Lab. No.	7-day test lbs. per sq. in.	28-day test lbs. per sq. in.	6-months test lbs. per sq.in.
2746	3-blend 293	357	...
2746	3-blend 287	433	437
2898	4-blend 240	355	367
2975	4-blend 250	322	333

The above cements were donated by the Texas Portland Cement Co. (Lone Star Brand), the Trinity Portland Cement Co. (Trinity Brand), the San Antonio Portland Cement Co. (Alamo Brand), and the Southwestern Portland Cement Co. (El Toro Brand), to whom thanks are extended.

While these tests show considerable variation in the cement used, the results on any one product should not be affected as the specimens were usually all made within a few days' time.

The sand used in the tests of the coarse aggregates is a clean, rather coarse, well graded Colorado River sand. This sand is composed of rounded and sharp grains of limestone, quartz, and feldspar, free from clay or loam. Three different shipments of this sand were used in these tests. The shipments were procured at different times, but the sand was of the same composition. The grading of these sands is shown on the curve on Plate I where the relative similarity of the grading is apparent.

Coarse aggregate permitting, concrete cylinders were made, using a standard Ottawa sand as the fine aggregate. This was done so that the test might easily be duplicated. As mentioned before, in testing sands for their mortar-making qualities, briquettes made with them were compared with the Ottawa sand briquettes.

The different grades of sand used in combination with the various aggregates in concrete were made by combining some fine Colorado River sand in definite proportions with a fine-grained quartz sand from Athens, Texas. These were combined so as to obtain a fine, and a medium fine, sand. This obtains a rather sharp sand free from clay or loam. The grading is also shown on Plate I.

The coarse aggregate used somewhat as a standard was a washed gravel, 50 per cent. of which passed 1½″ screen and was retained on the ¾″ screen, the remaining 50 per cent passed the ¾″ screen and was retained on the ¼″ screen. This gravel was graded from the Colorado River gravel and was therefore of like character, being composed of rounded and flat pebbles of limestone, granite, quartz, and feldspar. The limestone pebbles vary in hardness, some being rather soft, while others are quite hard.

In several tests a crusher-run trap rock aggregate with the the fine material removed was used. This was a very hard and tought rock, but was not particularly well graded. The grading of these aggregates are shown by the curves on Plate VIII.

Determination of Physical Properties of Aggregates

After the sample was received and numbered, the weight of a cubic foot of the material was obtained by shoveling it dry and loose in a 1-cubic foot box and leveling off the material without packing. After this was weighed, the aggregate was shaken to refusal by dropping the box until the material failed to settle further. Enough material was then added to fill the measuring box, and it was again weighed. The impact from dropping the box served to compact the dry material as a car of dry sand or stone is compacted in traveling a number of miles on a rather rough track. The weight per cubic foot was obtained only on dry material.

The method of making the specific gravity test of the aggregates differed according to the type of the material. The specific gravities of the sand and screenings were found by means of a LeChatelier bottle of the Bureau of Standards type. The specific gravity of the stone was obtained by the method of weighing the stone first in air and then in water, and calculating the specific gravity from loss in weight when immersed in the water. The weighing of the stone in the water was done quickly so that the stone absorbed practically no water. This was done by previously setting approximately correct weights on the balance before immersing the stone in the water. With the gravel aggregates the specific gravity was obtained by pouring a known weight of the gravel carefully into a graduate partly filled with water, and noting the amount of displaced water. The specific gravity was then calculated.

Knowing the weight per cubic foot and also the specific gravity of the aggregates, it is a simple calculation to determine the voids. The weight of a cubic foot of water, or 62.4 lbs., multiplied by the specific gravity (S) of the material, gives the weight of a cubic foot of the material if it were a solid block. Subtracting the weight per cubic foot of the aggregate obtained by weighing it (A) from this gives the weight of material that is required to fill the voids. This weight divided by the weight of a cubic foot solid times 100 is the per cent of voids, (V) in the aggregate.

$$V=\left(\frac{62.4\,S-A}{62.4\,S}\right)100$$

The compositions of the aggregates were examined by inspecting closely a number of individual particles, noting the kind of stone, its degree of hardness, the structure of the stones, and the amount of dust or loam contained. The uniformity of the aggregate is also an important consideration.

A mechanical analysis was then made on the aggregate to ascertain the grading of the material. The sample was quartered and requartered until a suitable portion of material was secured for the sieving test. With the coarse aggregates, screens having round openings were used. These screens were of the folowing sizes: 2", 1½", 1¼", 1", ½", ¼" and ⅛". The sieves used for the fine aggregates were of wire mesh of the Tyler Direct Ratio System, having the following sizes:

No. of sieve	Size of opening
10	0.065
20	0.0328
28	0.0232
35	0.0164
48	0.0116
65	0.0082
100	0.0058
200	0.0029

The grading test of fine aggregate was usually started on the ¼″ screen passing through all the sieves, including the No. 200. If any of the fine aggregates appeared dirty, they were washed and dried before making the analysis. The washing consisted of stirring the aggregates in water, and pouring off the water after allowing it to settle 20 seconds. The material washed out was considered as silt passing the No. 200 sieve. The curves of the grading of the various aggregates are given with their tests.

Making the Concrete

The Proportioning of the concrete was by volume. However, to insure accuracy, the materials were actually weighed, using the weight per cubic foot of dry material shoveled loose as a unit. A cubic foot of cement was considered as weighing 94 lbs., and referred to as one sack.

The Mixing of the concrete was done with shovels on account of the small batches it was necessary to handle. It was mixed on a concrete floor, which was practically non-absorbent. The sand and cement were mixed dry, until the mix was of uniform color, whereupon enough water was added to make a pasty mortar. The coarse aggregate, which had already been wet, was then added, and the whole batch turned until the stones were coated with mortar; enough water was added to give the concrete a medium consistency. At this stage the concrete was placed in the molds, previously oiled.

The Compression Test

The Compression Molds were made of No. 18 galvanized sheet iron, bent into cylinders 6 in. diameter and 12 in. high. The edges of the sheet iron that meet to complete the cylinder are bent outward into 1 in. flanges, which extend the full height of the cylinder. These flanges are held closed by clamps consisting of a 1″ cube of cast iron with a saw cut half way through. When the clamp is removed, there remains sufficient spring in the iron to open, allowing the mold to be removed with ease. A piece of oiled plate glass serves as a base for the molds, giving the specimen a plain surface. These molds are easily made and are light, making excellent field molds for contractors or engineers.

Enough concrete to fill the molds to a height of about 3 in. was placed in them at one time and tamped with a ⅝ in. round rod. After the molds were filled, they were allowed to remain without being disturbed for 24 hours. Then the forms were removed from the specimens and they were placed in wet sand. After being allowed to remain in the sand 6 days, they were removed and allowed to remain in air in the laboratory until tested. This method of making and curing the concrete was decided upon as being the nearest approach to actual practice in the field and yet in conformity with good laboratory practice.

Before testing the compression specimens the rough face was bedded in plaster of Paris on a glass plate in order that both surfaces of the specimens might have a plane surface. An Olsen 100,000 lb. testing machine, running at a speed of 0.05 inches per minute when unloaded, was used to test the specimens. A spherical bearing block was placed on top of the specimens to assure a direct line of pressure. Compression specimens that could not be broken in this machine were tested in the 400,000-lb. Riehlé Testing Machine, using the same methods.

The Tension Test

The tension specimens and abrasion ring were usually made out of the same batch and at the same time as the 1:2:4 concrete compression specimens. These specimens were also molded and stored in a similar manner. The mold used in making the tension specimens was made of No. 16 galvanized sheet iron, bent in the same shape as the standard cement briquettes. These specimens, however, were 5 in. sq. in section at the center. From this point the specimen gradually flared to a width of about 7 inches, and it was 12 in. long, and is shown in Fig. 1.

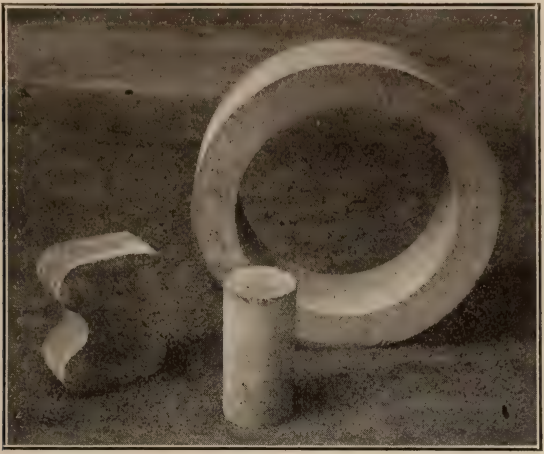

Fig. 1. Type of Specimens used in Compression, Tension, and Abrasion Tests.

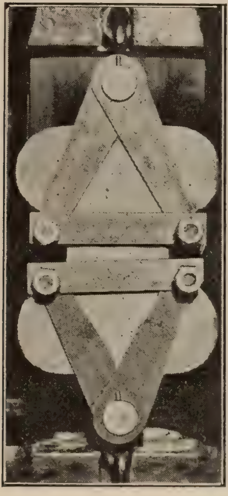

Fig. 2. Apparatus for Testing Specimens.

To test the concrete in tension, an apparatus was devised for holding the specimens so that the pull would be direct, without the presence of secondary stresses. See Fig. 2.

The speed of applying the tensile stress on the specimen varies from 1,000 to 1,200 lbs. per minute, which is at the rate of 40 to 48 lbs. per minute per square inch of the test specimen.

The Purpose of the Test

Concrete roads crack, in most cases, because of the low tensile strength of the material. The causes of this tensile stress are sometimes hard to determine, as it depends to a great extent on the condition of the subgrade and weather. A concrete road in setting will contract, due to the setting of the cement, unless counteracted by some other agency such as moisture or heat. Temperature also causes the contraction. In a monolithic road, when the friction on the subgrade is not sufficient to counterbalance this contraction, cracks will develop transversely in number and size, depending upon the resistance of the concrete of tensile stress, and also to the friction of the concrete with the subgrade. When laid in short slabs, separated by contraction joints at frequent intervals, the cracking will develop under similar conditions as in a monolithic road except that the slabs being much shorter fewer cracks will develop. A suitable condition might be where the concrete has a tendency to contract, the subgrade being in imperfect contact with the concrete except near the ends of the slab. This would give a condition similar to that in the test where the specimen is held at two ends and the center loose. This slab would crack at its weakest place, somewhere near its center where the friction is small. If the tensile strength of the concrete in the slab is great enough to resist the pull, no crack will develop, while in the monolothic slag the high tensile strength will decrease the number of transverse cracks. There is always considerable question as to the relative tensile strength of stone and gravel concrete. It was thought that the tensile strength tests on concrete might prove useful in helping solve such questions.

Reliability of the Tests

Specimens made using varying proportions of aggregates and cement were made on different days and tested at the same age, so that their average represents the average of specimens made in different atmospheric conditions. The results obtained follow:

Mix	Tensile strength lbs. per sq. in.				Maximum variation from average. per cent
				Avg.	
1 cement : 3 Ottawa sand	202	220	216	213	5.2
1 cement : 3 Colorado River sand	264	263	294	274	7.3
1 cement : 2 Colorado River sand : 4 Colorado River gravel	275	274	275	275	0.4
1 cement : 1½ Colorado River sand : 3 Colorado River gravel	288	304	280	291	4.0

From the above results it can be seen that the variation in the results in the tension tests is small. In fact, the maximum variation from the average results of a series of 3 specimens not reported here average but 8.6% in ten different series of specimens. Half of these series were stone and the other half were gravel, and they embraced variously proportioned concrete. These tests were made in connection with some other experiments and are not reported here.

In the tests included here it was only possible to make one tension specimen, due to the lack of material. However, on account of the relatively small error in the results shown above, it is believed one specimen serves the purpose.

The Abrasion Test

The Test Specimen—The test specimen was made in most cases from the same batch of concrete as the tension and the compression specimens. The test specimen was a concrete ring 20 in. inside diameter and 28 in. outside diameter, and 8 in. in breadth. The mold used was made of No. 16 galvanized sheet iron, bent to a circle 28 in. in diameter, similar to the compression specimens. The inside mold is also 8 in. high and bent to a circle 20 in. in diameter. The flanges on the inside mold are bent inward and a steel bar inserted between the flanges, keeping them about 1 in. apart when the concrete is being molded. The mold is removed by removing the bar and pulling the flanges together, thus making the diameter of the mold less than that of the specimen, so that it can be easily slipped out. To make this mold rigid, while the wet concrete was being placed, a wooden frame was built around the outside mold, and the inside one was held in place by means of U-shaped iron strips placed on top of the mold. As the mold was filled with concrete, these strips were removed. This proved very satisfactory. This should make a very good mold for field work as it is comparatively light and easily handled. A more satisfactory one for laboratory use is one made from cast iron. Both of these molds are shown in Fig. 3.

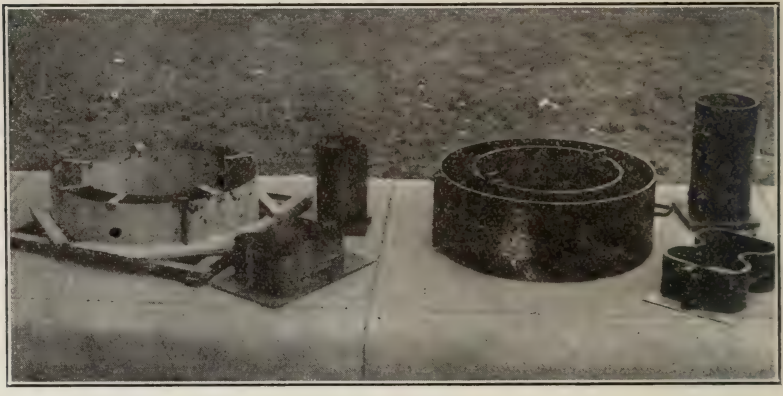

Fig. 3. Types of Moulds used in making Specimens.

Like other specimens, the concrete ring, one day after being poured, was stored in wet sand for 6 days, then in air until tested. The machine used for testing these specimens was the old style brick rattler with one moving head. The abrasive agent consisted of 139 cubical cast iron shot with rounded corners 1½ in. on a side, averaging 13.2 oz. per shot, and 6 cast iron shot with rounded edges 4½ in. x 2⅝ in., weighing 7¼ lbs. The total charge, therefore, weighed 158 lbs.

Testing the Specimen.

In the rattler alternate staves were removed in order to lighten the load on the pulley. The specimen was placed tight against one end of the rattler, then the shot was placed in the specimen and the moving head brought into contact with the other face of the concrete ring, thereby inclosing the shot in a circular chamber, with the concrete surface to be tested as the circular wall. Wooden wedges were driven between the concrete ring and the staves, in order that the axis of the specimen would be in line with the axis of the rattler. Fig. 4.

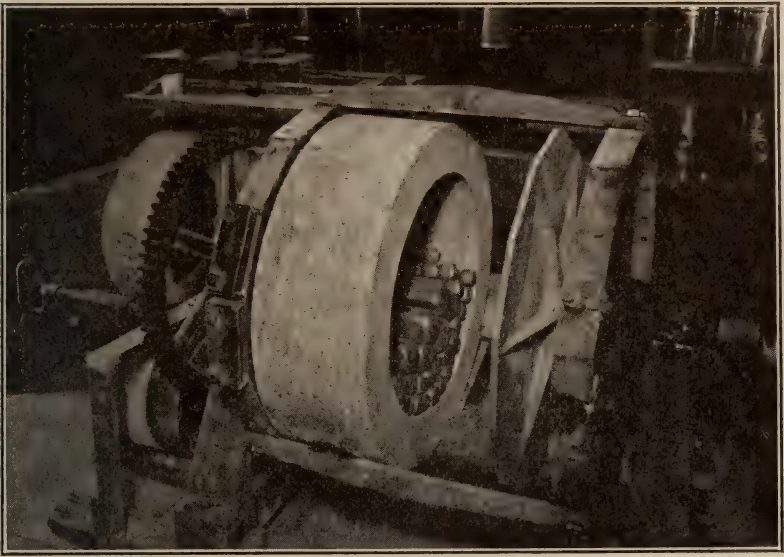

Fig. 4. Machine used in making Abrasion Tests.

The specimen was run for 2,000 revolutions in a test. After each 500 revolutions it was weighed, but the percentage loss in weight was figured upon the basis of 1,000 revolutions in all cases. After the first specimen was run, it was deemed advisable to use some reinforcing in the ring to enable the specimen to resist the strains imposed upon it during the test so that two 3/8″ round bars were used as reinforcement.

After the abrasion tests, the surface of the specimen was examined thoroughly and its appearance noted. It is considered that the appearance of the specimen after the test is of equal importance with the percentage loss in weight, as it is this character of the surface which gives an idea of the character of the road surface after it has been in use for some time.

Reliability of Results

As might be expected, the individual results show considerable variation from the average; much more than with the tension tests. The amount of this variation is given by the following tests of specimens made in every way the same except on different days:

1 part cement : 2 parts Colorado River sand : 4 parts Colorado River gravel. Age 28 days.

1st specimen lost 3.81 per cent by weight in 1,000 revolutions.
2nd specimen lost 3.70 per cent by weight in 1,000 revolutions.
3rd specimen lost 2.88 per cent by weight in 1,000 revolutions.

Avg., 3.46 per cent.
The maximum variation from the average is 16.8 per cent.

1 part cement : 2 parts Colorado River sand : 4 parts crushed limestone (¼″ - 1½″)

1st specimen lost 1.74 per cent by weight in 1,000 revolutions.
2nd specimen lost 2.25 per cent by weight in 1,000 revolutions.
3rd specimen lost 1.97 per cent by weight in 1,000 revolutions.

Avg., 1.98 per cent.
The maximum variation from the average is 13 per cent.

Results

The results of the tests on each product are given independently as they are not directly comparable. Table I, however, presents averages of the various types of aggregates with the maximum and minimum results obtained. The many factors affecting the strength and density of the concrete are not considered in the averages. These results are at least interesting. The average shows in a general way that considerable cement is saved by using gravel instead of crushed stone. This amounts to approximately ½ sack per cubic yard of laid concrete. More water is required with the crushed stone than with the gravel. The rounded pebbles of the gravel are easily lubricated and require less water to get the same consistency.

An attempt was made to give a sufficient number of tests using the various mixes to enable one to judge the effects obtained by still further changes in the mixes. It is generally recognized, other things being equal, that the concrete having the greatest density is the strongest, but, it will readily be seen that no definite proportion of fine to coarse aggregates will give the maximum density for all materials. The proportion is dependent upon the grading and character of the aggregates themselves.

Concrete made in the field usually is mixed somewhat wetter than that in the laboratory, which would tend to give it a lower compressive strength. However, it is reasonable to assume that the relationship between the concrete made in the field and that made in the laboratory is relatively constant.

As a general proposition, there seems to be no relation between the compression, tension, and abrasion tests, although the number of tests made is somewhat limited for judging.

In the abrasion test it is as important that the character of the surface be known as it is to know the numerical loss; for a most important consideration with a concrete road is to produce a surface that will wear uniformly. It is necessary that the road surface be always smooth enough to allow the vehicles to pass over the road without appreciable impact. On the other hand, it should be rough enough to allow horses a good footing, which is needed particularly on wet days and on steep grades.

The Gravel Aggregates

Considering the results of the materials tested without determining reasons, it is apparent that the gravel aggregates in the 1:2:4 mixes produced slightly stronger concrete than did the crushed limestone aggregates. This is true in spite of the fact that the gravel concrete when made from the fixed proportions as above, requires from ¼ to ½ sack less cement per cubic yard of laid concrete than does the crushed stone.

With the abrasion tests, most of the surfaces of the gravel specimens were rough. Such gravels as No. 2930-A and No. 2732 containing pebbles of varying hardness, produce a rough surface in which the hard flints wear but little while the softer limestones wear equally with the mortar. Fig. 5. In some cases flints protrued as much as ½″ above the surrounding surface. Other gravels such as No. 2765, composed of uniformly hard pebbles, produce a surface which is uniform but extremely rough as the motar wears much faster than the stones themselves. Many of the harder stones are knocked out of the surface, causing a pitting and loss in the specimen above normal. Sample No. 2872 presents a different type of gravel. This is essentially a limestone gravel in which the pebbles are but little harder, if any, than the mortar and consequently the surface of abrasion specimen wore very uniformly. With this gravel, it should be noted, however that practically no pebbles over 1¼ in. were present, which undoubtedly influence the satisfactory results.

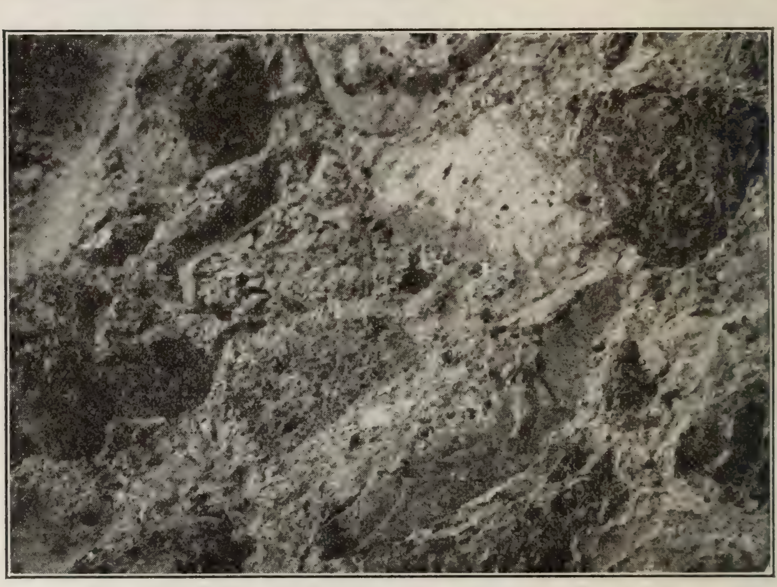

Fig. 5. Character of Gravel Surface Concrete after Test.

The tensile strength of the concrete made from the gravels does not seem to be inferior to the tensile strength of crushed stone, as might be expected; neither does it seem to be greater.

Crushed Stone Aggregates

The limestone aggregates tested were all of rather soft material, some of the limestone, however, being harder than others. Practically all of the limestones would, when tested, have a French Coefficient between 6 and 11 and a compressive strength between 7000 and 16,000 lbs. per sq. inch. As far as the com-

TABLE OF AVERAGES

Table showing the avtrage amount of cement and water required, weight per cubit foot, and compression strength of concrete using various aggregates used in Texas

Coarse Aggregate	Mix	No. of tests averaged	No. of sacks of cement per cu. yard			Weight per cu. ft. of concrete			Water used	Crushing Strength, 28 days			Crushing Strength, 6 months		
			Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Avg.	Max.	Min.	Avg.	Max.	Min.
Limestone	1:3:6	5	4.25	4.34	4.08	143.7	146.5	141	9.59	1,643	2,400	1,112	1,800	2,285	1,190
Gravel	1:3:6	5	3.81	3.94	3.68	147.3	154	144.5	7.01	1,908	2,220	1,310	1,749	2,000	1,350
Trap rock	1:3:6	1	4.34	--------	--------	157.5	--------	--------	9.51	1,500	--------	--------	--------	--------	--------
Slag	1:3:6	1	4.60	--------	--------	141	--------	--------	8.2	2,385	2,630	--------	--------	--------	--------
Limestone	1:2:4	18	6.06	6.28	5.56	143.7	149	138	9.55	2,584	3,302	1,785	2,726	3,635	2,060
Gravel	1:2:4	17	5.56	5.83	5.18	147.3	154.5	143	7.90	2,611	3,670	1,730	2,824	3,580	2,210
Trap rock	1:2:4	2	5.91	--------	--------	160.3	--------	--------	8.49	2,785	--------	--------	3,285	--------	--------
Slag	1:2:4	3	6.26	--------	--------	144.2	--------	--------	--------	--------	--------	--------	--------	--------	--------
Pit run gravel	1:4	5	6.74	7.45	6.22	147.6	152.3	144	11.45	2,619	3,600	1,635	--------	--------	--------
Pit run gravel	1:6	4	4.74	5.28	4.03	143.4	146.5	138	9.8	1,672	--------	--------	--------	--------	--------

pressive strength is concerned, it is believed that the difference in strength of the limestone beyond a certain limit had no appreciable effect on the compressive strength of the concrete.

The surfaces of the limestone abrasion specimens were as a rule smooth and uniform, the stone wearing equally with the mortar. In a specimen made of limestone No. 2830, where the aggregate contained some larger stones, the surface was somewhat wavy, due to the fact that the larger stones refused to wear with the smaller pieces. In the limestone specimens where the aggregate was below 1½ in. in size, the surfaces were very satifactory (Fig. 6). In one or two specimens containing some unusually soft stones, there was a tendency for these softer stones to be pitted. However, this did not seem to be any serious disadvantage in the test specimens, but it might develop more seriously in a road surface.

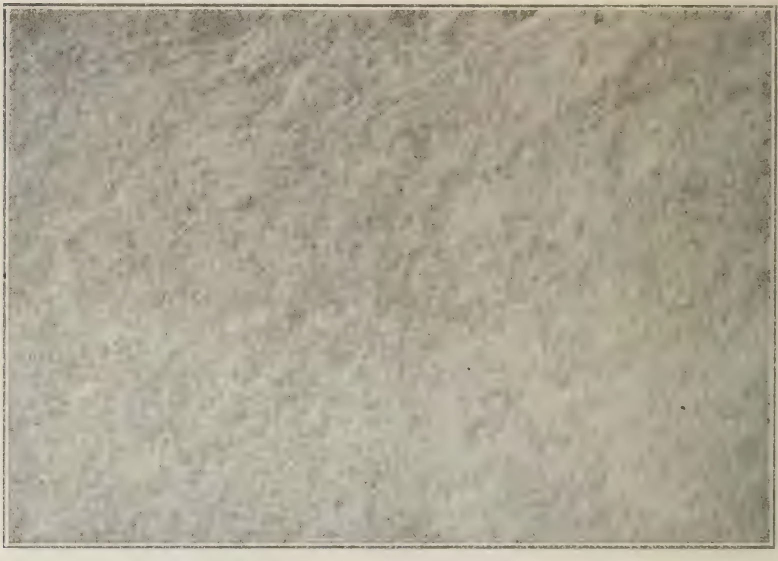

Fig. 6. Character of Limestone Concrete Surface after Test.

The crushed trap rock compression specimens developed no more strength than the limestone or gravel specimens. The aggregate was rather poorly graded as can be seen from the analysis. With the abrasion tests, however, the results are interesting. All the trap rock tested was from the Texas Trap

Rock Company, and was very hard and tough, having a hardness coefficient* of 17.5 and toughness of 15. It has also a high resistance to wear in the Duval abrasion machine, the French coefficient of wear being 22.2. In the 1:2:4 concrete specimens the mortar wore faster than the stones, giving the surface a distinctly mosaic appearance. With the larger sized aggregates this is more noticeable.

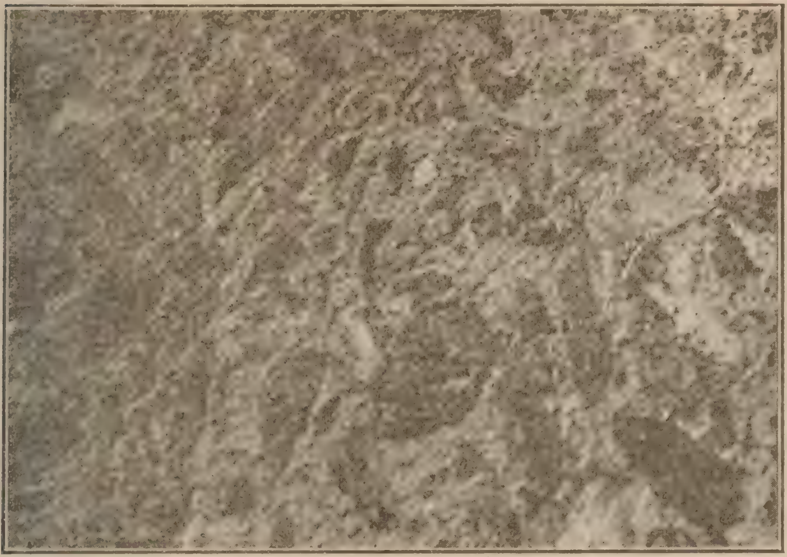

Fig. 7. Character of Trap Rock Concrete Surface after Test.

With the richer 1:1½:3 specimens, the mosaic appearance was still apparent when the larger sized aggregates were used, but when the aggregate was limited to 1 in. in size, the surface was very uniform, having but few protruding stones. This later specimen also had a high resistance to wear. See Fig. 7.

The one sample of crushed blast furnace slag is interesting. Concrete made with this slag had a rather high compressive strength. It should be noted, however, that the slag was exceptionally well graded. The comparative lightness of this material is worthy of note not only in handling the aggregate, but also as it reduces the weight of the resultant concrete an appreciable extent.

---

*See the University of Texas Bulletin No. 62, Road Materials of Texas.

The abrasion specimen wore quite uniformly, except some of the larger stones protruded. The specimen also showed a rather high resistance to abrasion. The surface of the specimen appeared rather porous, due to the fact that the surfaces of stones exposed were worn away, exposing the interior. It would seem that such a surface as this should be very satisfactory for a surface treatment of oil, asphalt, or tar.

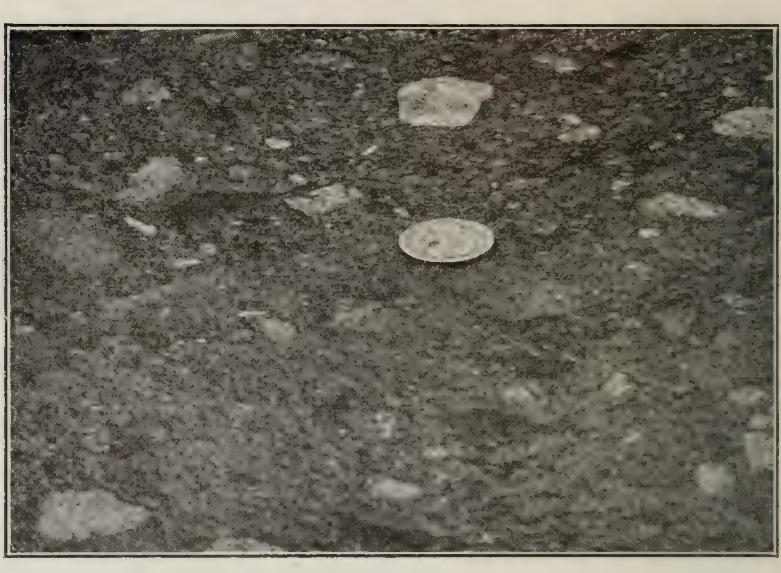

Fig. 8. Concrete Street Crossing showing hard Flints protruding from Surface.

Character of Road Surfaces Compared with Abrasion Specimens

There is considerable similarity between the results obtained in the laboratory and those shown in actual construction. San Pedro Avenue in San Antonio, Texas, was constructed about four years ago of a concrete composed of one part cement, three parts of a medium fine sand, six parts of a soft local limestone. This street carries a fairly heavy traffic and today is in excellent condition, being smooth and free from depressions. While this is a poorer concrete than any of the concretes tested, the appearance of the surface is practically the same as that of the surface of the limestone specimens. The surface of this street would seem to indicate that when a soft stone is used, the aggregate also should be weak, so that both should wear equally.

On North Laredo Street in the same city a trap rock concrete has been in use for something less than two years. The proportions of the concrete were 1:2:4 mix, the stone being the same trap rock as that used in the laboratory tests, except that it was graded from ¼″ to 2″. The condition of the surface of the street, however, brings out the similarity of the wear with that of the laboratory specimens. The mortar is wearing rapidly away from the stones, leaving them protruding from the surface. The large size stone used aided this result considerably, it is believed.

A crossing for pedestrians on a fairly heavy traffic street in Austin, Texas, is illustrated in Fig. 8. This is a gravel concrete in which the flints protrude while the limestone pebbles have worn equally with the mortar. The gravel in this section was the same as that in specimen No. 2821, though the proportion of the mortar was different.

While the above are the only examples at hand illustrating these tests, the writer has been informed of many others which bring out the various points shown by the laboratory tests.

Recommendations

While these tests are a matter of recording certain data regarding the possibilities of various aggregates for concrete making, there are some more or less definite conclusions that may be stated. No attempt was made to establish any new principles regarding the strength of concrete, but rather to establish a working basis for the production of the most satisfactory concrete from the aggregates as they are commericially produced.

It is recommended that engineers provide themselves with cylinderical molds similar to those previously described and have frequent tests made on specimens of the concrete going into the structure, whatever it might be.

The method of making and curing the test specimens is described at some length in the bulletin as a guide to those making specimens in the field. Results thus obtained can be correlated with those given here and it will soon be found that superior concrete can be made without additional expense by observing the fundamental principles given in text books on this subject. The essential thing, however, is to know what quality concrete one is obtaining and then to improve this quality. This can be done by frequent tests and observance of the concrete as it is laid.

The method recommended by the authorities on concrete as being the most practical and efficient is worthwhile repeating here, as these tests emphasize the correctness of the method of proportioning concrete. It is recommended that the best aggregates obtainable at reasonable cost should be used and these should be proportioned by trial, keeping the amount of cement the same in each instance, and the mix which gives the maximum density will give the maximum strength provided, of course, it produces workable concrete.

It is recommended that a clause be inserted into specifications regarding proportions for concrete to read something like this:

"The proportions of the cement to the sand and the sand to the coarse aggregate shall be determined in the presence of the engineer by mixing trial batches in the proportions of 1:1.6:4.4, 1:1.8:4.2, 1:2:4, 1:2.2:3.8, etc., until the mix giving maximum density is found. In any event, the cement content per yard of laid concrete shall not be less than 5½ sacks for gravel concrete or not less than 5¾ for stone or slag concrete."

Should it be desired to obtain concrete having the cement content and strength of a 1:1½:3 mix the proportions of the mix should, of course, be changed to read 1:1.3:3.2, 1:1.5:3, 1:1.7:2.8, etc., and the cement content changed to read "not less than 7½ sacks or more than 7¾ sacks for gravel, or not less than 7¾ sacks or more than 8 sacks for stone or slag." Similarly for concrete of the type obtained from 1:3:6 mix the proportioning should be 1:28:62, 1:3:6, 1:32:58, etc., with the cement content changed to read not less than 4 or more than 4¼ sacks for gravel concrete and not less than 4¼ or more than 4½ sacks for stone or slag concrete.

This is satisfactory for both the engineer and the contractor, as it assures the engineer of obtaining the best concrete from the available materials and it assures the contractor of the amount of cement the work will require and he can bid accordingly. If the engineer assures himself that the aggregate to be used is satisfactory from the standpoint of durability, cleanliness, grading and such properties, he can be assured of obtaining good concrete and can design accordingly.

Attention should be called to the fact that the aggregates should be sized so that the fine and coarse aggregate meet, but do not overlap. That is if the coarse aggregate is graded from 1½″ to ¼″, the sand should be graded up to ¼″, or if the coarse aggregate is graded to ⅛″ then the sand should likewise be graded to this size and no larger. This should be taken care of in the specifications.

A clause requiring the minimum amount of water to be used that will produce smooth workable concrete should be also included in the specifications.

Two essentials for a satisfactory concrete road are, (1) uniformity of wear; (2) a minimum of wear. Whenever these two are combined with a high tensile strength, the most satisfactory concrete road is found.

With the aggregate for a concrete road, however, certain conclusions may be drawn from the tests, as follows:

Uniformity of wear is found when the mortar and the coarse aggregate wear equally. In other words, a hard, tough trap rock requires a stronger mortar than a rather soft limestone, but the former will wear proportionately less than the latter, other things being equal.

The tests would indicate that the coarse aggregate should be limited to 1½ in. in size. In practice, however, the traffic has less tendancy to dig into the surface than the shot do in the test specimens, so that this limit might well be raised to 2″ for the softer stones.

Judging from the results of the use of hard, tough coarse aggregates in the abrasion tests, it would seem that a limit of 1″ in the size stones used should be placed and the cement content increased. In practice this limit also might well be raised to 1½″ or 2″ if a rich mix is to be used.

Crushed slag, when hard and uniform, should be satisfactory as a concrete road aggregate from the standpoint of wear.

In a 1:2:4 concrete, made with a gravel containing uniformly hard pebbles, such as flint and quartz, the surface wears rough in the test specimens, and if the aggregate is composed of some hard and some softer pebbles, the surface wears rough and uneven.

The action of the cubical shot on the test specimen is a trifle more severe than the action of traffic on the road. The corners of the shot, even though they are rounded, butt into the mortar to a greater extent than does the traffic.

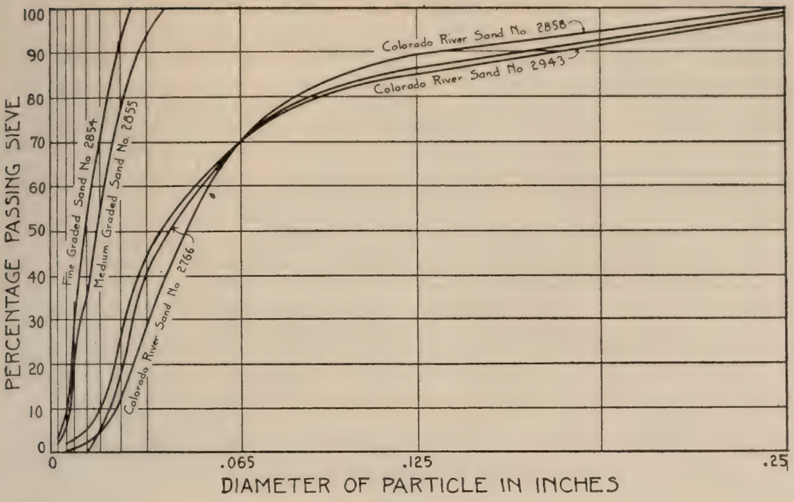

Plate I.

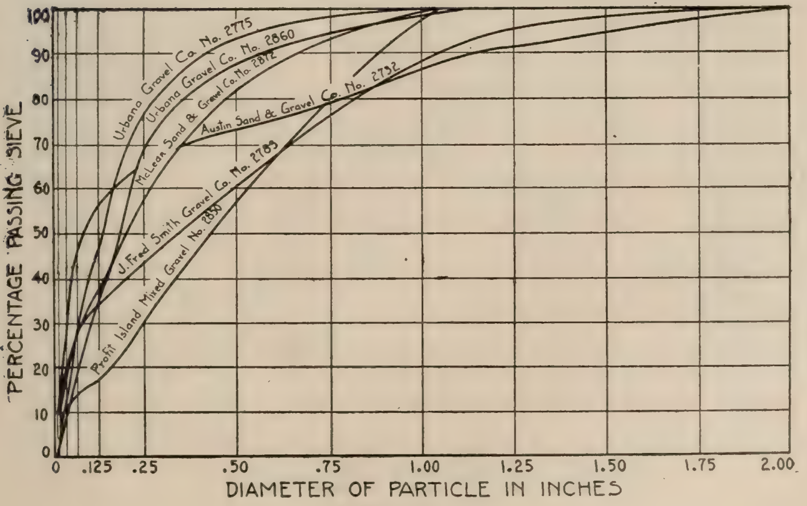

Plate II.

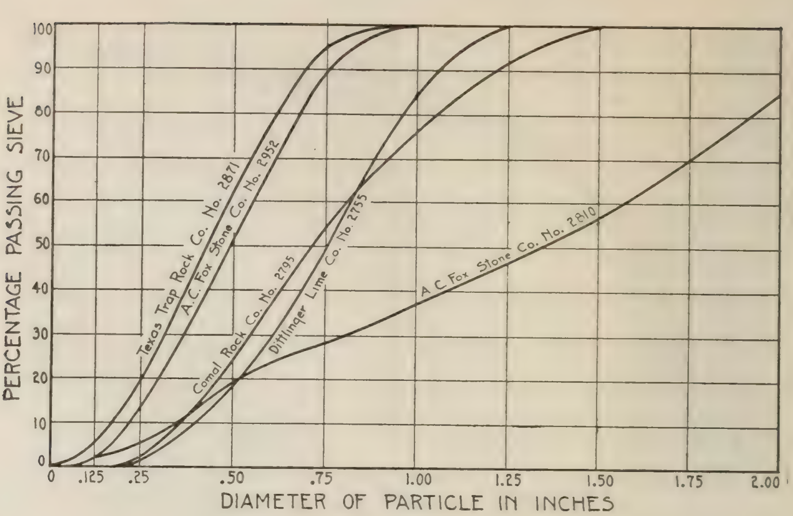

Plate III.

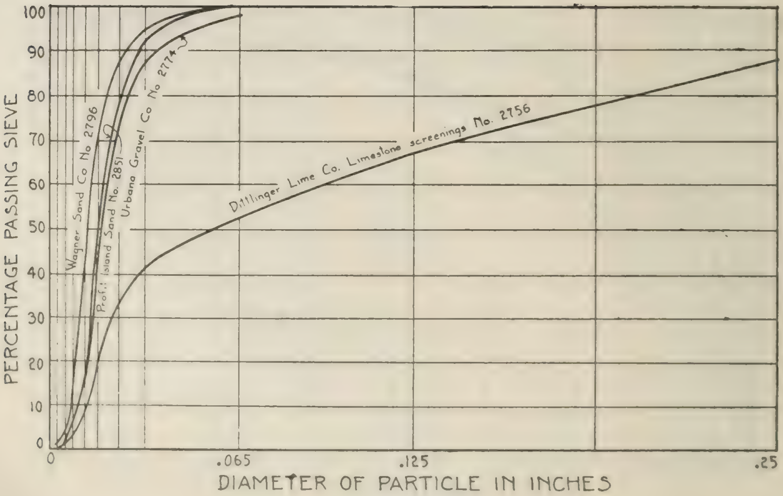

Plate IV.

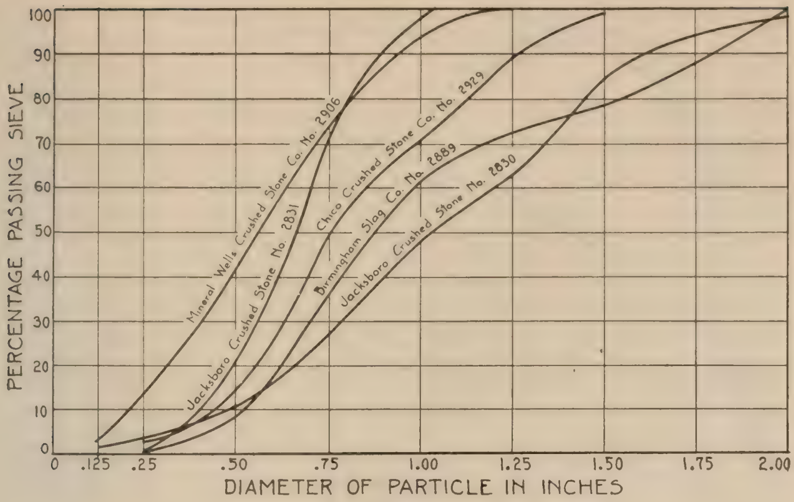

Plate V.

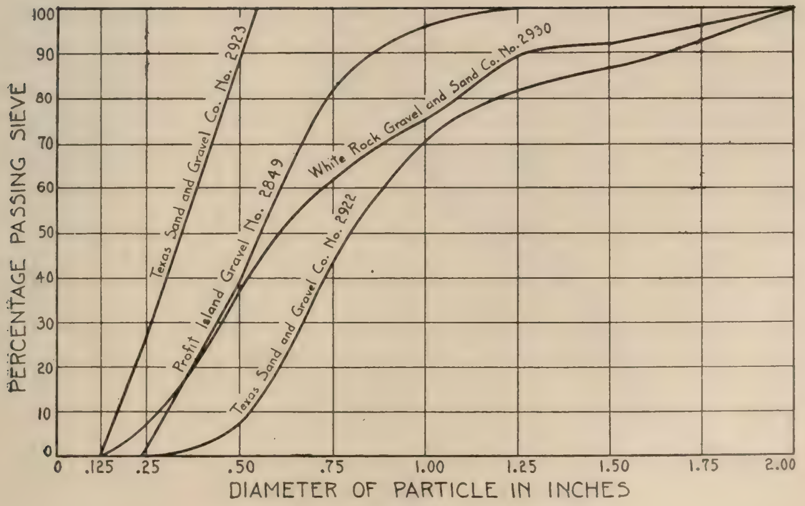

Plate VI.

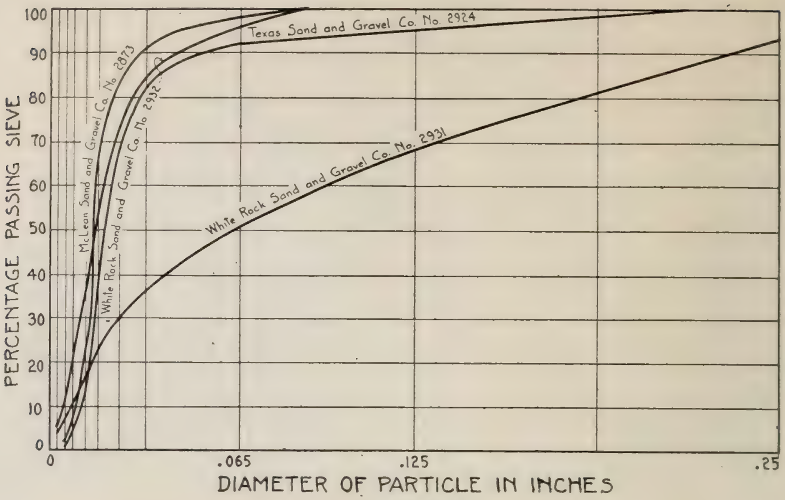

Plate VII.

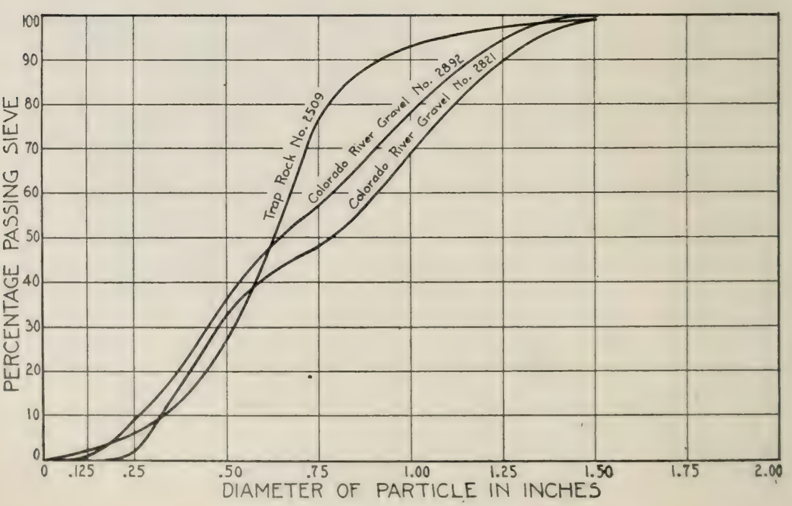

Plate VIII.

RESULTS OF TESTS

The materials tested and the results following include the great volume of the materials produced in the State for concrete. The tests are given separately for each material as they are not strictly comparative. In all cases where it is possible to do so, full data is given regarding the water used, age, crushing strength, number of specimens tested, weight of concrete and amount of cement per cubic yard of laid concrete. The percentage of water used in the concrete is the weight of water compared to the weight of the dry ingredients. The strength tests are all given in pounds per square inch. The number of tests included in the average is given in parenthesis, after the crushing strength. Among other data is given the weight of a cubic foot of the concrete one day after it is molded. In most cases this weight was ascertained by weighing the total concrete made from the mix and dividing this by the volume. The specimens were actually weighed; the volume was ascertained by measuring the specimens and calculating their volume. In a number of earlier tests this was not done, and the weight per cubic foot was ascertained by assuming the dimensions of the specimens. These are given as approximate values and are so marked by the abbreviation, ''approx.'' The amount of cement per cubic yard of laid concrete was calculated from the volume of the resulting concrete and the amount of cement used. Like the weight of the concrete, this was approximated in some cases which are so marked. The errors resulting are small, and it is believed that none are over 4%.

Laboratory number 2732.

Material—Pit run gravel under 2 inches.

Producer—Austin Sand and Gravel Co., Austin, Texas.

Character of Aggregate—The gravel is made up of pebbles of quartz, flint, granite and gneiss with considerable soft and hard limestone, the flints and limestones predominating. About half the stones are rather flat, while the remainder are well rounded. The gravel contains considerable sand, but is free from clay or silt.

Mechanical Analysis—The following analysis indicates that this gravel contains about twice as much sand as it does coarse gravel. (Plate II.)

Mechanical Analysis

Retained on 2″ screen	0%
Passing 2″ screen and retained on 1½″ screen	5%
Passing 1½″ screen and retained on 1¼″ screen	4%
Passing 1¼″ screen and retained on 1″ screen	4%
Passing 1″ screen and retained on ¾″ screen	8%
Passing ¾″ screen and retained on ½″ screen	6%
Passing ½″ screen and retained on ¼″ screen	7%

Coarse aggregate=34% of total.

Passing ¼″ screen and retained on ⅛″ screen	11%
Passing ⅛″ screen and retained on No. 10 sieve	8%
Passing No. 10 sieve and retained on No. 20 sieve	21%
Passing No. 20 sieve and retained on No. 28 sieve	9%
Passing No. 28 sieve and retained on No. 35 sieve	5%
Passing No. 35 sieve and retained on No. 48 sieve	5%
Passing No. 48 sieve and retained on No. 65 sieve	3%
Passing No. 65 sieve and retained on No. 100 sieve	3%
Passing No. 100 sieve and retained on No. 200 sieve	1%
Passing No. 200 sieve	0%
Total	100%

Sand=66% of total.

Weight of loose wet pit-run gravel is 100½ lbs. per cu. ft. or 2710 lbs. per cu. yd.

Weight of loose dry pit-run gravel is 110½ lbs. per cu. ft. or 2980 lbs. per cu. yd.

Weight of packed dry pit-run gravel is 113¼ lbs. per cu. ft. or 3060 lbs. per cu. yd.

Voids in loose pit-run gravel, 29%.

Voids in packed pit-run gravel, 28%.
Specific gravity, 2.52.
Cement used in these tests was blend cement No. 2746.

1:4 mix (used 10.4% water), approx. 6.4 sacks cement.
28-day test.........2,980 lbs. per sq. in. (2)

Approx. wt. 138 lbs. per cu. ft. 1:6 mix (used 11.2% water),
Approx. 4.6 sacks cement
28-day test.........1,645 lbs. per sq. in. (2)

The above pit run gravel was screened through a ¼″ sieve to separate the coarse aggregate from the sand and these aggregates were tested separately and recombined in definite proportions.

The Sand

The feature of this sand is that it is a coarse well graded sand, has very little material below the No. 48 sieve.

The Mechanical Analysis.

Retained on ¼″ screen	0%
Passing ¼″ screen and retained on ⅛″ screen	17%
Passing ⅛″ screen and retained on No. 10 sieve	12%
Passing No. 10 sieve and retained on No. 20 sieve	32%
Passing No. 20 sieve and retained on No. 28 sieve	14%
Passing No. 28 sieve and retained on No. 35 sieve	8%
Passing No. 35 sieve and retained on No. 48 sieve	8%
Passing No. 48 sieve and retained on No. 65 sieve	4%
Passing No. 65 sieve and retained on No. 100 sieve	3%
Passing No. 100 sieve and retained on No. 200 sieve	2%
Passing No. 200 sieve	0%

Loose dry sand weighed 102¾ lbs. per cu. ft. or 2,770 lbs. per cu. yd.

Voids in loose sand are 36%.

Specific gravity, 2.53.

The mortar-making qualities are shown by the following tests:

Tensile strength briquettes. 1 : 3 mix by weight.

	This sand (9.8% water used)	Standard Ottawa sand (9.3% water used)
7-day tests	388 lbs. per sq. in. (3)	273 lbs. per sq. in. (3)
28-day tests	452 lbs. per sq. in. (3)	347 lbs. per sq. in. (3)
6-months tests	537 lbs. per sq. in. (3)	388 lbs. per sq. in. (3)

Compressive strength cubes. 1 : 3 mix by weight.

	This sand (9.8% water used)	Standard Ottawa sand (9.3% water used)
28-day tests	5,200 lbs. per sq. in. (2)	2,888 lbs. per sq. in. (2)
6-months tests	5,425 lbs. per sq. in. (1)	4,650 lbs. per sq. in. (1)

The relation of the strength of this sand to that of Ottawa sand in mortar is as follows:

	Compressive strength	Tensile strength
7-day test	.....	142%
28-day tests	180%	130%
6-months tests	117%	138%

These tests indicate that this is a superior sand for mortar, and that when used, with the proper coarse aggregates, it should make a high quality of concrete.

The Mechanical Analysis indicates that this is a fairly well graded gravel and is as follows:

Retained on 2″ screen	0%
Passing 2″ screen and retained on 1½″ screen	15%
Passing 1½″ screen and retained on 1¼″ screen	12%
Passing 1¼″ screen and retained on 1″ screen	12%
Passing 1″ screen and retained on ¾″ screen	23%
Passing ¾″ screen and retained on ½″ screen	18%
Passing ½″ screen and retained on ¼″ screen	20%
	100%

Weight of loose dry gravel is 102 lbs. per cu. ft. or 2760 lbs. per cu. yd.

Voids in loose gravel equal 34.5%.

Specific gravity equals 2.50.

Using this screened sand and gravel with cement No. 2746, concrete was obtained which when tested resulted as follows:

1 : 2 : 4 mix (used 7.5% water). Approx. wt. 144 lbs. per cu. ft.
Approx. 5.18 sacks cement per yd. concrete.

28-day test	3,100 lbs. per sq. in.
6-months test	3,050 lbs. per sq. in.

1 : 3 : 6 mix (using 6.5% water). Approx. wt. 144½ lbs. per cu. ft.
Approx. 3.68 sacks per yd. concrete.

28-day tests	2,220 lbs. per sq. in. (2)
6-months tests	1,835 lbs. per sq. in. (2)

Tension test. 1:2:4 mix (7.5% water)

30-day test ....268 lbs. per sq. in.

Abrasion test. 1 : 2 : 4 mix (used 7.4% water).

The loss in weight at 1,000 revolutions was..................4.7%

After the run, the surface was very rough, the limestone pebbles in the gravel wearing the same amount as the mortar, but the flint and quartz stones remain almost without wear, however, some of them were knocked out of the concrete which resulted in a small hole in the surface. The granite pieces crack and chips fall out, but do not wear in the sense that the limestone pebbles wear.

Remarks: The 1:4 concrete using the pit-run gravel is actually a 1 : 2 ¾ : 1 ½ mix, while the 1:6 mix is really a 1:4½:2¼, which contains considerable more sand than is considered satisfactory for good concrete.

Comparing the screened gravel concrete with the pit-run gravel concrete:

Mix	Crushing strength at 28 days lbs. per sq. in.	Increase in strength lbs. per sq. in.	No. of sacks of cement per cu. yd. of concrete	No. of sacks of cement saved
1 : 4	2,980	120	6.40	1.22
1 : 2 : 4	3,100	...	5.18	....
1 : 6	1,645	575	4.60	.92
1 : 3 : 6	2,220	...	3.68	....

It is, therefore, seen that in spite of the saving in cement in the screened and remixed gravel concrete, the latter obtains stronger concrete.

Laboratory Number—2755.

Material—Crushed limestone between 1¼″ and ¼″.

Producer—Dittlinger Lime Co., New Braunfels, Comal Co., Texas.

Character of Aggregate—The stones making up this aggregate are angular fragments of fairly hard limestone, but the aggregate also contains a considerable quantity of soft stones.

Mechanical Analysis—That this is a fairly well graded aggregate between 1¼″ and ¼″ and free from dust is shown by the mechanical analysis as follows: (Plate III.)

Retained on 1¼″ screen	0%
Passing 1¼″ screen and retained on 1″ screen	16%
Passing 1″ screen and retained on ¾″ screen	35%
Passing ¾″ screen and retained on ½″ screen	31%
Passing ½″ screen and retained on ¼″ screen	17%
Passing ¼″ screen	1%
	100%

Weight of loose dry stone is 82¾ lbs. per cu. ft. or 2,240 lbs. per cu. yd.

Weight of packed dry stone is 87 lbs. per cu. ft. or 2,340 lbs. per cu. yd.

Voids in loose stone equal 49%.

Voids in packed stone equal 46½%.

Specific gravity, 2.62.

Cement used in these tests was blend cement No. 2746.

Sand used in these tests was Colorado River sand No. 2766.

Screenings used in these tests were Dittlinger screenings No. 2756 (report follows).

Compression tests made using this crushed limestone as the coarse aggregate and Colorado River sand No. 2766 as fine aggregate, resulted as follows:

1 : 2 : 4 mix (wet consistency). Approx. wt. 148 lbs. per cu. ft. Approx. 6.6 sacks cement.

28-day test .... 2,600 lbs. per sq. in. (2)
6-months test .... 3,125 lbs. per sq. in. (2)

1 : 3 : 6 mix (used 8.4% water; wet consistency). Approx. wt. 146 lbs. per cu. ft. Approx. 4.16 sacks cement.

28-day tests .... 1,695 lbs. per sq. in.
6-months tests .... 1,815 lbs. per sq. in.

Using the same crushed stone and Dittlinger screenings No. 2756, the following strengths were obtained:

1 : 2 : 4 mix (used 9.5% water). Approx. wt. 146 lbs. per cu. ft. Approx. 5.96 sacks cement.

28-day tests .... 2,670 lbs. per sq. in. (2)
6-months tests .... 3,170 lbs. per sq. in. (2)

1 : 3 : 6 mix (used 10% water). Approx. wt. 143½ lbs. per cu. ft. Approx. 4.15 sacks cement.

28-day tests .... 1,190 lbs. per sq. in. (2)
6-months tests .... 1,365 lbs. per sq. in. (2)

The above results lead to the conclusion that this is a satisfactory coarse aggregate from the standpoint of compressive strength. When the screenings are used as a fine aggregate, it is necessary to use considerable more water in mixing to obtain the same consistency.

Proportion	Using this stone and sand No. 2766	Using this stone and screenings No. 2756
1:1.4:4.6	3,980 lbs. per sq. in.	....
1:1.6:4.4	4,200 lbs. per sq. in.	1,750 lbs. per sq. in.
1:1.8:4.2	4,550 lbs. per sq. in.	3,100 lbs. per sq. in.
1:2:4	3,020 lbs. per sq. in.	2,640 lbs. per sq. in.
1:2.2:3.8	3,430 lbs. per sq. in.	2,100 lbs. per sq. in.

These values are the result of but one test of each specimen, 6″ in diameter, 6¼″ high in the case of sand concrete and 7″ high in the case of the screenings concrete. While the actual results should not be considered as the strength of this concrete, due to the insufficient size and number of test specimens, the relative results are not impared. Cylinders having the height equal to the diameter have about 16% greater strength than those whose height is twice the diameter. This shows the 1:1.8:4.2 concrete to be the most satisfactory in both cases from the standpoint of strength.

Tension Tests. Specimens made from batch as compression specimens of same mix.

1:2:4 mix

Crushed stone with Colorado River sand No. 2766

28-day tests............................236 lbs. per sq. in (1)

Crushed with Dittlinger screenings No. 2756

28-day tests............................222 lbs. per sq. in. (1)

Abrasion Test

Using Dittlinger Crushed Stone and Colorado River Sand, results as follows:

1:2:4 mix (used 8.8% wet consistency)

28-day tests showed a loss in 1,000 revolutions of..........3.63%

The surface of the abrasion ring after the run was uniform, the stones having worn equal in amount to the mortar, so that the surface was free from bumps or hollow places. This uniformity in wear is very essential in any road, as it assures a true and even surface even though the wear be considerable.

Laboratory Number—2756.

Material—Limestone Screenings.

Producer—Dittlinger Lime Company.

Character of Aggregate—The screenings are composed of angular fragments of limestone, similar to the crushed stone.

Mechanical Analysis—This test shows the screenings to be coarse and well graded as follows: (Plate IV.)

Retained on ¼″ screen	13%
Passing ¼″ screen and retained on ⅛″ screen	20%
Passing ⅛″ screen and retained on No. 10 sieve	11%
Passing No. 10 sieve and retained on No. 20 sieve	15%
Passing No. 20 sieve and retained on No. 28 sieve	8%
Passing No. 28 sieve and retained on No. 35 sieve	13%
Passing No. 35 sieve and retained on No. 48 sieve	12%
Passing No. 48 sieve and retained on No. 65 sieve	5%
Passing No. 65 sieve and retained on No. 100 sieve	2%
Passing No. 100 sieve and retained on No. 200 sieve	1%
Passing No. 200 sieve	0%
	100%

Weight of loose dry screenings is 93 lbs per cu. ft. or 2510 lbs. per cu. yd.

Weight of packed dry screenings is 102 lbs. per cu. ft. or 2,750 lbs. per cu. yd.

Voids in loose screenings equals 42%.

Voids in packed screenings equals 36½%.

Specific gravity, 2.58.

The cement used in these tests is blend cement, No. 2,746.

The mortar making qualities of these screenings is shown by the following tests.

Tensile strength briquettes
1:3 mix by weight

	These screenings	Standard Ottowa sand
7-day tests	339 lbs. per sq. in. (3)	246 lbs. per sq. in. (3)
28-day tests	462 lbs. per sp. in. (3)	342 lbs. per sq. in. (3)
6-months tests	472 lbs. per sq. in. (3)	350 lbs. per sq. in. (3)

Compressive strength cubes
1:3 mix by weight

	These screenings	Standard Ottowa sand
27-day tests	3,256 lbs. per sq. in. (2)	2,363 lbs. per sq. in. (2)
6-months tests	4,475 lbs. per sq. in. (1)	4,025 lbs. per sq. in. (1)

The relation of the strength of the mortar made with these screenings to that of Ottowa sand is as follows:

	Compressive strength	Tensile strenth
7 day tests	———	138%
27-day tests	138%	135%
6-months tests	111%	135%

These tests show that the screenings are very satisfactory for mortar. In using this mortar with a coarse aggregate to form concrete, it is necessary to take precautions to have the coarse aggregate so graded that a dense concrete will be produced. There is a great tendency for the concrete to ''pocket.'' In practice it has been found advantageous to mix a fine sand with screenings, thus producing an aggregate which is easier to work. Tests using these screenings in concrete are given in the preceding report.

Laboratory Number—2765.

Material—Washed gravel between 2″ and ¼″.

Producer—Horton and Horton Gravel Co., Houston, Texas.

Character of Aggregate—Consists of more or less rounded pebbles of flint and quartz with a small amount of limestone and feldspar.

The stones are smooth and free from clay or loam.

The Mechanical Analysis—The tests were made on two shipments of this gravel which show considerable difference in their grading as shown by the following analysis.

	First shipment	Second shipment
Retained on 2″ screen	6%	0%
Passing 2″ screen retained on 1½″ screen	0%	14%
Passing 1½″ screen retained on 1¼″ screen	9%	13%
Passing 1¼″ screen retained on 1″ screen	7%	23%
Passing 1″ screen retained on ¾″ screen	5%	17%
Passing ¾″ screen retained on ½″ screen	9%	18%
Passing ½″ screen retained on ¼″ screen	40%	13%
Passing ¼″ screen retained on ⅛″ screen	17%	1%
Passing ⅛″ screen	7%	1%
	100%	100%

Weight of dry loose gravel 101 lbs. per cu. ft. or 2,730 lbs. per cu. yd.

Weight of dry packed gravel 104¼ lbs. per cu. ft. or 2,820 lbs. per cu. yd.

Voids in loose gravel 37%.

Voids in packed gravel 34½%.

Specific gravity equals 2.58.

The cement used in these tests was blend cement No. 2,746.

The sands used were: Colorado River sand No. 2,766; Standard Ottowa sand; fine sand No. 2,854; medium sand No. 2,855.

Compression tests of concrete made with the gravel of the first shipment gave the following results:

Using Colorado River sand No. 2,766
1:3:6 mix (used 6.83% water)
Approx. wt. 145 lbs per cu ft. Approx. 3,71 sacks cement.
28-day tests........................2,055 lbs. per sq. in. (2)
6-months tests......................1,810 lbs. per sq. in. (2)
1:2:4 mix (used 7.45% water)
Approx. wt. 146.5 lbs. per cu. ft. Approx. 5.35 sacks cement.
28- day test ....2,860 lbs. per sq. in. (2)
6-months test ....2,990 lbs. per sq. in. (2)
Using Standard Ottowa sand
1:2:4 mix (used 7.2% water)
28-day tests........................2,990 lbs. per sq. in. (2)
Using medium sand No. 2,855
1:2:4 mix (used 9.5% water)
28-day tests........................2,080 lbs. per sq. in. (2)
Using fine sand No. 2,854
1:2:4 mix (used 9.4% water)
28-day tests........................2,270 lbs. per sq. in. (2)

The drop in strength using the finer sands is quite characteristic and shows the value of using a coarse well-graded sand. The results of the compression test show that this is a very satisfactory aggregate for concrete in compression.

Tension tests on concrete
1:2:4 mix (used 7.45% water)
28-day tests..........................222 lbs per sq. in. (1)

The abrasion test on concrete made with second shipment of gravel:
1:2:4 mix (used 6.5% water)
28-day test ....2.75% loss in weight

The condition of the surface of the concrete was quite rough after the test; the hard flint pebbles remaining practically in same condition as they were before the run while the mortar wore away. A number of stones were knocked out leaving small holes while the limestone pebbles wore equal in amount to the mortar. Some stones protruded as much as ⅜″ above the surrounding surface of the specimen.

An absorption test made upon the concrete at the age of 6 months showed an absorption of 2.95%. The specimen, however, was not dried at an elevated temperature, but had remained indoors 6 months previous to the test.

Laboratory Number—2783.

Material—Pit-run gravel under 2″.

Producer—J. Fred Smith Gravel Co., Farmers Branch, Dallas Co., Texas.

Character of Aggregate—Consists of rounded and flat pebbles of limestone, ferrugenous sandstones and some shell, well graded. The finer particles are quartz and calcareous sand free from clay. To some of the larger pebbles a layer of sand is cemented with a calcareous deposit.

Mechanical Analysis—Exceptionally well graded for pit-run gravel below 1½ in., grading as follows: (Plate II.)

Retained on 2″ screen	0%
Passing 2″ screen and retained on 1½″ screen	3%
Passing 1½″ screen and retained on 1¼″ screen	2%
Passing 1¼″ screen and retained on 1″ screen	8%
Passing 1″ screen and retained on ¾″ screen	12%
Passing ¾″ screen and retained on ½″ screen	16%
Passing ½″ screen and retained on ¼″ screen	16%

Coarse aggregate 57% of total.

Retained on ¼″ screen

Passing ¼″ screen and retained on ⅛″ screen	10%
Passing ⅛″ screen and retained on No. 10 sieve	5%
Passing No. 10 screen and retained on No. 20 sieve	6%
Passing No. 20 screen and retained on No. 28 sieve	5%
Passing No. 28 screen and retained on No. 35 sieve	8%
Passing No. 35 screen and retained on No. 48 sieve	6%
Passing No. 48 screen and retained on No. 65 sieve	2%
Passing No. 65 screen and retained on No. 100 sieve	1%
Passing No. 100 screen and retained on No. 200 sieve	0%
Passing No. 200 screen	0%
Sand 43% of total.	100%

Weight of dry loose pit-run gravel is 122½ lbs. per cu. ft. or 3,310 lbs. per cu. yd.

Weight of dry packed pit-run gravel is 129¾ lbs. per cu. ft. or 3,500 lbs. per cu. yd.

Voids in loose pit-run gravel equals 27%.
Voids in packed pit-run gravel equals 23%.
Specific gravity 2.70.
The cement used in these tests was blend cement No. 2,746.
Compression tests of concrete made with this pit-run gravel.

1:4 mix (used 8.0% water)
Approx. 152¼ lbs. per cu ft. Approx. 6.62 sacks cement.
28-day tests..........................3,600 lbs. per sq. in. (2)

1:6 mix (used 8.4% water)
28-day tests..........................2,240 lbs. per sq. in. (2)

Had the pit-run gravel been screened through ¼″ sieve and remixed the proportions of the mix would have been as follows:

1:6 mix is equivalent to a 1:2.45:4.9 or slightly richer than a 1:2½:5.

1:4 mix is equivalent to a 1:1.6:3.2 or slightly leaner than a 1:1½:3.

This pit-run gravel was sieved through a ¼″ square mesh sieve to separate the coarse aggregate from the sand, and tests were made on these aggregates separately and after having been recombined in definite proportions in concrete.

The Sand.

Mechanical Analysis—A coarse well-graded sand with little passing the No. 48 sieve.

Retained on ¼″ screen	0%
Passing ¼″ screen and retained on ⅛″ screen	23%
Passing ⅛″ screen and retained on No. 10 sieve	12%
Passing No. 10 sieve and retained on No. 20 sieve	14%
Passing No. 20 sieve and retained on No. 28 sieve	12%
Passing No. 28 sieve and retained on No. 35 sieve	18%
Passing No. 35 sieve and retained on No. 48 sieve	14%
Passing No. 48 sieve and retained on No. 65 sieve	5%
Passing No. 65 sieve and retained on No. 100 sieve	2%
Passing No. 100 sieve and retained on No. 200 sieve	0%
Passing No. 200 sieve	0%
	100%

Weight of dry loose sand is 113½ lbs. per cu. ft. or 3070 lbs. per cu. yd.

Voids in loose sand equal.

Specific gravity equals.

Concrete compression specimens using this sand and a well-graded Colorado River Gravel No. 2821.

1:2:4 mix (used 7.35% water). Approx. wt. 152 lbs. per cu. ft.
Approx. 5.5 sacks of cement.
28-day tests ....3,670 lbs. per sq. in. (2)
6-months tests ....3,580 lbs. per sq. in. (3)

Using this sand and crushed trap rock No. 2569
1:2:4 mix (used 7.16% water). Approx. wt. 165 lbs. per cu. ft.
Approx. 5.84 sacks cement.
28-day tests ....3,270 lbs. per sq. in. (2)
6-months tests ....3,850 lbs. per sq. in. (1)

A 6″ cylinder 7″ high at 6 months broke at 4,260 lbs. per sq. in., which is 11% higher than a 6″x12″ cylinder.

From the results of these tests it appears that this sand below ¼″ is an excellent concrete making sand when used with good coarse aggregates.

The Gravel

Mechanical Analysis—This is a well graded gravel below 1½″ as shown by the following:

Retained on 2″ screen	0%
Passing 2″ screen and retained on 1½″ screen	5%
Passing 1½″ screen and retained on 1¼″ screen	4%
Passing 1¼″ screen and retained on 1″ screen	14%
Passing 1″ screen and retained on ¾″ screen	21%
Passing ¾″ screen and retained on ½″ screen	28%
Passing ½″ screen and retained on ¼″ screen	28%
	100%

Weight of dry loose gravel is 94¼ lbs. per cu. ft. or 2,540 lbs. per cu. yd.

Using this screened sand and screened gravel aggregates for concrete the following results were obtained:

1:3:6 mix (medium consistency). Approx. 154 lbs. per cu. ft.
Approx. 3.94 sacks cement.
28-day tests ....2,045 lbs. per sq. in. (2)
6-months tests ....2,000 lbs. per sq. in. (1)

1:2:4 mix (used 7.4% water)
Approx. 154½ lbs. per cu. ft. Approx. 5.62 sacks cement.
28-day tests ....3,290 lbs. per sq. in. (2)
6-months tests ....3,290 lbs. per sq. in. (2)

Abrasion test
1:2:4 mix (used 7.4% water)
28-day tests.............4.13% loss in weight in 1,000 revolutions

The surface of the specimen after the run appeared somewhat uneven due to a number of swellings and hollow places, but there were no extremely rough places. Several stones protruded from the surface and a number were knocked out, however, the surface was more uniform than with hard gravel concrete, due to the fact that the gravel was made up mostly of limestone pebbles, which wore evenly with the mortar.

An absorption test made on the 1:2:4 concrete showed a gain in weight of 3.57%. The specimen was dried in the oven but had been stored indoors for 6 months previous to the test.

Laboratory Number—2795.

Material—Crushed limestone 1½″ to ¼″.

Producer—Comal Rock Co., New Braunfels, Comal Co., Texas.

Character of Aggregate—Crushed limestone mixed up of sharp angular fragments of limestone with some soft stones.

The Mechanical Analysis—Indicates that this is a well graded aggregate between 1¼″ and ¼″ in size as follows: (Plate III.)

Retained on 1½″ screen	0%
Passing 1½″ screen retained on 1¼″ screen	8%
Passing 1¼″ screen retained on 1″ screen	16%
Passing 1″ screen retained on ¾″ screen	22%
Passing ¾″ screen retained on ½″ screen	30%
Passing ½″ screen retained on ¼″ screen	22%
Passing ¼″ screen retained on ⅛″ screen	1%
Passing ⅛″ screen	1%
	100%

Weight of dry loose stone is 78½ lbs. per cu. ft or 2,120 lbs. per cu. yd.

Weight of dry packed stone is 85¾ lbs per cu. ft. or 2,320 lbs. per cu. yd.

Voids in loose stone equals 52½%.

Voids in packed stone equals 48%.

Specific gravity equals 2.65.

Cement used in these tests is blend cement No. 2,746.

Sand used in this test is Colorado River sand No. 2,766, Standard Ottowa sand, medium sand No. 2,855, fine sand No. 2,854.

Compression tests
1:2:4 mix (used 7.6% water)
Approx. wt. 148 lbs. per cu. ft. Approx. 6.21 sacks cement
28-day test............................3,265 lbs. per sq. in. (2)
6-months test..........................3,635 lbs. per sq. in. (2)

Varying the proportions of sand to stone but keeping the sum of the two the same when measured separately, and also using the same proportion of cement in each case, the following results were obtained:

1:1.6:4.4 mix (used 7.9% water)
Wt. 148½ lbs. per cu. ft. 6.27 sacks cement.
28-day test............................3,080 lbs. per sq. in. (2)
1:1.8:4.2 mix (used 7.9% water)
Wt. 148 lbs. per cu. ft. 6.22 sacks cement
28 day test............................3,270 lbs. per sq in. (2)
1:2:4 mix (used 7.8% water)
Wt. 147 lbs. per cu. ft. 6.12 sacks cement
28-day test............................3,340 lbs. per sq. in. (2)
1:2.2:3.8 (used 8.6% water)
Wt. 145½ lbs. per cu ft. 5.96 sacks cement.
28-day test............................2,690 lbs. per sq. in. (2)
1:2.4:3.6 (used 8.7% water)
Wt. 143½ lbs. per cu. ft. 578 sacks cement
28-day test............................2,710 lbs. per sq. in. (2)

From these results it appears that the 1:2:4 mix or the 1:1.8:4.2 mix gives the most satisfactory concrete; however, the 1:2:4 mix having slightly more sand would work easier in mixing and placing. It would appear that the 1:1. 6:4.4 mix gives maximum density, but the difference between this and the 1:1.8:4.2 mix is small enough to be within the range of experimental error.

Varying the grading of the sand, but keeping the coarse aggregate the same, the following results were obtained.

Using well-graded Colorado River sand (average of the two tests above).

1:2:4 mix (used 7.7% water)
Wt. 147½ lbs. per cu. ft. 6.17 sacks cement
28-day test............................3,302 lbs. per sq. in. (4)
Using Standard Ottowa sand
1:2:4 mix (used 8.3% water)
Approx. wt. 149 lbs. per cu ft. Approx. 6.28 sacks cement
28-day test............................3,450 lbs. per sq. in. (2)

1:2:4 mix (used 10% water)

Approx. wt. 147 lbs. per cu. ft. Approx. 6.17 sacks cement

28-day test..........................3,020 lbs per sq. in.

Using fine sand

1:2:4 mix (used 10.2% water)

Wt. Approx. 145 lbs. per cu. ft. Approx. 6.07 sacks cement

28-day test..........................2,510 lbs. per sq. in. (2)

Disregarding the Ottawa sand it appears that a coarse, well-graded, clean sand is the most satisfactory type of sand to use with this stone.

The tension test

1:2:4 mix (used 7.6% water)

28-day test..............................284 lbs. per sq. in.

The abrasion test

1:2:4 mix (used 7.6% water)

28-day test............lost 3.01% by weight in 1,000 revolutions.

The surface of the specimen wore rather uniformly having no deep depressions or swellings. Where exceptionally large stones were located near the surface a slight swelling developed, while soft stones unless surrounded by harder stones caused a slight depression, on the whole a rather satisfactory surface.

The absorption test made on 1:2:4 concrete after it had remained indoors in air for six months showed an absorption of 2.98% by weight.

Laboratory Number—2796.

Material—Sand.

Producer—Wagner Sand Company, San Antonio, Texas.

Character of Aggregate—Composed of fine, sharp, angular grains of quartz, free from clay or loam.

Mechanical Analysis—A rather fine graded sand not especially well graded as shown by the following analysis: (Plate IV.)

Retained on ⅛″ screen	0%
Passing ⅛″ screen retained on No. 10 sieve	1%
Passing No. 10 sieve retained on No. 20 sieve	4%
Passing No. 20 sieve retained on No. 28 sieve	9%
Passing No. 28 sieve retained on No. 35 sieve	15%
Passing No. 35 sieve retained on No. 48 sieve	29%
Passing No. 48 sieve retained on No. 65 sieve	25%
Passing No. 65 sieve retained on No. 100 sieve	13%
Passing No. 100 sieve retained on No. 200 sieve	3%
Passing No. 200 sieve	1%
	100%

Weight of dry loose sand is 91¼ lbs. per cu. ft. or 2,460 lbs. per cu. yd.

Weight of dry packed sand is 100 lbs per cu. ft. or 2,700 lbs. per cu. yd.

Voids in loose sand equal 44%.

Voids in packed sand equal 39%.

Specific gravity equals 2.64.

Cement used in these tests was blend cement No. 2,746.

Gravel used in these tests was well graded Colorado River gravel No. 2,821.

Mortar making qualities of this sand:

Tensile strength

1:3 mix by weight (used 11.6% water)

	This sand	Standard Ottowa sand
7-day tests	250 (4)	285 (4)
28-day tests	290 (4)	409 (4)
6-months tests	354 (4)	444 (4)

Compressive strength on two inch cubes

	This sand	Standard Ottowa sand
7-day test	1,630 lbs. per sq. in. (4)	2,090 lbs. per sp. in. (4)
27-day test	2,325 lbs. per sq. in. (4)	3,019 lbs. per sq. in. (4)
6-months test	3,340 lbs. per sq. in. (4)	4,053 lbs. per sq. in (4)

The relation of the strength of this sand to that of Ottawa sand is as follows:

	Compressive strength	Tensile strength
7-day test	78%	77%
28-day test	88%	71%
6-months test	80%	82%

These indicate that more cement should be used with this sand to make mortar equal in strength with that made with the coarser graded sands.

Concrete made from this sand using well graded Colorado River gravel for coarse aggregate.

1:2:4 mix (used 9.0% water)

Wt. 143 lbs. per cu. ft. 5.55 sacks cement.

28-day tests	2,460 lbs. per sq. in. (2)
6-months test	2,583 lbs. per sq. in. (3)

Using this same gravel as coarse aggregate and a well graded Colorado River sand 2,858, the following results were obtained:

1:2:4 mix (used 7.5% water)

Approx. wt. 147 lbs. per cu. ft. Approx. 5.48 sacks cement

28-day tests	2,720 lbs. per sq. in.
6-months tests	2,970 lbs. per sq. in.

Laboratory Number—2810.

Material—Crushed Limestone 2½″ to ¼″.

Producer—A. C. Fox Stone Quarry, Lueders, Jones Co.

Character of Aggregate — Composed of flat and angular fragments of limestone rather low in hardness, but uniform in quality.

Mechanical Analysis—Indicates that this stone is very well graded from 2½″ to ⅛″ and free from dust, as follows: (Plate III.)

Retained on 2″ screen	15%
Passing 2″ screen and retained on 1½″ screen	28%
Passing 1½″ screen and retained on 1¼″ screen	10%
Passing 1¼″ screen and retained on 1″ screen	10%
Passing 1″ screen and retained on ¾″ screen	9%
Passing ¾″ screen and retained on ½″ screen	9%
Passing ½″ screen and retained on ¼″ screen	14%
Passing ¼″ screen and retained on ⅛″ screen	3%
Passing ⅛″ screen	2%
	100%

Weight of dry loose stone is 74 lbs. per cu. ft. or 2,000 lbs. per cu. yd.

Weight of dry packed stone is 85 lbs. per cu. ft. or 2,300 lbs. per cu yd.

Voids in loose stone equal 52%.

Voids in packed stone equal 45%.

Specific gravity equals 2.49.

Cement used in these tests was blend cement No. 2,746.

Sands used in these tests were Colorado River sand No. 2,766, Standard Ottowa sand, medium sand No. 2,855, fine sand No. 2,854.

Concrete made using this material as the coarse aggregate and Colorado River sand as the fine aggregate, showed the following results in compression.

1:3:6 mix (used 7.84% water)
Approx. wt. 143½ lbs. per cu. ft. Approx. 4.34 sacks cement
28-day tests.........................2,000 lbs. per sq. in. (2)
6-months test.......................2,215 lbs. per sq. in. (2)

1:2:4 mix (used 7.6% water)
Approx. wt. 144½ lbs. per cu. ft. Approx. 6.22 sacks cement
28-day tests.........................3,260 lbs. per sq. in. (2)
6-months tests.....................3,150 lbs. per sq. in. (2)

These results indicate a very satisfactory concrete aggregate. Concrete made using this coarse aggregate with various grades of sand showed the following results in compression:

1:2:4 mix (used 8.8% water)
Using Standard Ottowa sand
Wt. 146 lbs. per cu. ft. 6.28 sacks cement.
28-day test............................3,520 lbs. per sq. in. (2)
1:2:4 mix (used 10.9% water)
Using medium sand.
Wt. 143½ lbs. per cu. ft. 6.12 sacks cement.
28-day test............................2,940 lbs. per sq. in. (2)
Using fine sand
Wt. 142½ lbs. per cu. ft. 6.11 sacks cement
28-day test............................3,010 lbs. per sq. in. (2)

The Abrasion Test.

The stones above 1½″ were screened out as aggregate above this size have not been considered as satisfactory for road work as that below 1½″ in size.

1:2:4 mix (medium consistency)
28-day test..............lost 3.98% in weight in 1000 revolutions

The surface of the specimen after this test was very satisfactory, being uniform, showing only very slight swellings or depressions. The only flaw in the surface was a hole caused by an air void in the concrete due to insufficient spading when the specimen was molded.

The absorption test made on the 1:2:4 concrete after remaining in air indoors for 6 months showed an absorption of 3.93%.

Laboratory Number—2952.

Material—Crushed limestone 1″ to ⅛″.

Producer—A. C. Fox ,Stone Co., Leuders, Jones County Texas.

Character of Aggregate—Consists of somewhat soft. flat, angular fragments of limestone, uniform in quality and with a small amount of dust.

Mechanical Analysis—A rather well graded aggregate. (Plate III.)

Retain on 1″ screen	0%
Passing 1″ screen retained on ¾″ screen	10%
Passing ¾″ screen retained on ½″ screen	39%
Passing ½″ screen retained on ¼″ screen	38%
Passing ¼″ screen retained on ⅛″ screen	11%
Passing ⅛″ screen	2%
	100%

Weight of dry loose stone is 69 lbs. per cu. ft. or 1,860 lbs. per cu. yd.

Weight of dry packed stone is 76½ lbs per cu. ft. or 2,060 lbs. per cu. yd.

Voids in loose stone equals 55%.

Voids in packed stone equals 51%.

Specific gravity equals 2.50.

Cement used in these tests was blend cement No. 2,898.

Sands used in these tests are Colorado River sand No. 2,943 except material over ⅛″ screen was removed. Standard Ottowa sand, medium sand No. 2,855, fine sand No. 2,854.

Compression test

Using Colorado River sand under ⅛″

1:3:6 mix (used 12.3% water)

Approx. wt. 141 lbs. per cu ft. 4.40 sacks cement

28-day test........1,112 lbs. per sq. in. (2)

6 months test........1,290 lbs. per sq. in. (2)

1:2:4 mix (used 11.8% water)

Wt. 140 lbs. per cu. ft. 6.09 sacks cement

28-day test........1,785 lbs. per sq. in. (2)

6 months test........2,285 lbs. per sq. in. (2)

Using Standard Ottowa sand

1:2:4 mix (used 10.7% water)

Wt. 142½ lbs. per cu. ft. 6.26 sacks cement

28-day test........2,280 lbs. per sq. in. (2)

1:2:4 mix (used 12.1% water)

Wt. 138½ lbs. per cu. ft. 6.11 sacks cement

28-day test........2,235 lbs. per sq. in.

Using fine sand

1:2:4 mix (used 12.5% water)

Wt. 138 lbs. per cu. ft. 6.06 sacks cement

28-day tests........2,270 lbs. per sq. in. (2)

Tension test

Colorado River sand under ⅛″

1:2:4 mix (used 11.8% water)

28-day tests........232 lbs. per sq. in.

Abrasion test
Using Colorado River sand under ⅛″.
1:2:4 mix (used 11.8% water)
28-day test...............lost 4.8% by weight in 1,000 revolutions

The surface of the specimen after this test was very satisfactory, being comparatively smooth.

The absorbtion tests made on the 1:2:4 concrete after remaining in air indoors for 6 months showed an absorption of 5:51 per cent.

Laboratory Number—2830.

Material—Crushed limestone from 2″ to ¼″.

Producer— Risley Bros., Jacksboro, Texas, Jack County.

Character of Aggregate—Consists of angular fragments of limestone; intermingled are a number of soft fragments.

Mechanical Analysis—A fairly well graded aggregate from 2″ down to ¼″ as follows: (Plate V.)

Retained on 2″ screen	3%
Passing 2″ screen retained on 1½″ screen	13%
Passing 1½″ screen retained on 1¼″ screen	22%
Passing 1¼″ screen retained on 1″ screen	13%
Passing 1″ screen retained on ¾″ screen	21%
Passing ¾″ screen retained on ½″ screen	17%
Passing ½″ screen retained on ¼″ screen	8%
Passing ¼″ screen retained on ⅛″ screen	2%
Passing ⅛″ screen	1%
	100%

Weight of dry loose stone is 79¼ lbs. per cu. ft. or 2,140 lbs. per cu yd.

Weight of dry packed stone is 86 lbs per cu. ft. or 2,320 lbs. per cu yd.

Voids in loose stone equal 50%.

Voids in packed stone equal 46%.

Specific gravity equals 2.55.

Cement used in these tests was blend cement No. 2,746.

Sand used in these tests was Colorado River sand No. 2,858.

Compression tests
Using Colorado River sand and this coarse aggregate.
1:3:6 mix (used 8.0% water)
Wt. 146½ lbs. per cu. ft. 4.27 sacks cement.
28-day test..........................2,400 lbs. per sq. in. (2)

1:2:4 mix (used 12.1% water)

Approx. wt. 144½ lbs. per cu. ft. Approx. 5.82 sacks cement

28-day tests..........................2,460 lbs. per sq. in. (2)

6-months tests........................2,735 lbs. per sq. in. (2)

From the above results, it is apparent that this aggregate is satisfactory for concrete.

Tension test

1:2:4 mix (used 12.1% water)

28-day tests................................288 lbs per sq in.

Abrasion test

1:2:4 mix (used 12.1% water)

28-day test.............loss 4.03% by weight in 1,000 revolutions

The surface of the abrasion ring was somewhat rough after the test, due to the fact that the larger stones failed to wear equal in amount with the smaller stones and mortar. The protruding of any of the larger stone from the surrounding surface was in no case as much as ¼″.

The absorption test made on 1:2:4 concrete after remaining in air in doors for 6 months absorbed 4.68 per cent water by weight.

Laboratory Number—2831.

Material—Crushed limestone from 1¼″ to ¼″.

Producer—Risley Bros., Jacksboro, Jack Co.

Character of Aggregate—Consists of angular fragments of limestone, a small proportion of which is soft stones.

Mechanical Analysis—A fairly well graded aggregate between 1″ and ¼″ in size, graded as follows: (Plate V.)

Retained on 1¼″ between	0%
Passing 1¼″ screen retained on 1″ screen	2%
Passing 1″ screen retained on ¾″ screen	25%
Passing ¾″ screen retained on ½″ screen	53%
Passing ½″ screen retained on ¼″ screen	19%
Passing ¼″ screen	1%
	100%

Weight of dry loose stone is 78 lbs. per cu. ft. or 2,110 lbs. per cu. yd.

Weight of dry packed stone is 83 lbs. per cu. ft. or 2,240 lbs. per cu. yd.

Void in loose stone equals 52½%.

Voids in packed stone equals 49½%.

Specific gravity 2.65.

Cement used in these tests was blend cement No. 2,898.

Sand used in these tests was Colorado River sand No. 2,858.

Compression tests using Colorado River sand and this coarse aggregate.

1:3:6 mix (used 10.6% water)

Approx. wt. 141½ lbs. per cu. ft. Approx. 4.08 sacks cement

28-day tests.........................1,340 lbs. per sq. in. (2)

6-months tests.........................1,525 lbs. per sq. in. (2)

1:2:4 mix (used 9.8% water)

Approx. wt. 146 lbs. per cu. ft. Approx. 6.04 sacks cement.

28-day tests.........................2,120 lbs. per sq. in. (2)

6-months tests.........................2,310 lbs. per sq. ft. (2)

From these tests it is apparent that this aggregate does not make as strong concrete as the larger sized stone.

Tension test

1:2:4 mix (used 9.8% water)

28-day tests..............................230 lbs. per sq. in.

Abrasion test

1:2:4 mix (used 9.8% water)

28-day tests...........lost 3.67% by weight in 1,000 revolutions

The surface of the specimen after the run was was very uniform and free from depressions, as the limestone had worn equal in amount as the mortar. The surace was better than in the specimen in which the larger sized aggregate was used.

An absorption test made on the 1:2:4 concrete after it had remained in air 6 months showed an absorption of 4.48% water by weight.

Laboratory Number—2849.

Material—Profit Island washed gravel from 1″ to ¼″.

Producer—J. W. Thompson, New Orleans, La.

Character of Aggregate—Consists of pebbles of quartz, chert and flint, which are clean and smooth. A number of stones show indications of having been crushed.

Mechanical Analysis—Fairly well graded gravel from 1″ to ¼″, as follows: (Plate VI.)

Retained on 1¼″ screen	0%
Passing 1¼″ screen retained on 1″ screen	5%
Passing 1″ screen retained on ¾″ screen	13%
Passing ¾″ screen retained on ½″ screen	43%
Passing ½″ screen retained on ¼″ screen	37%
Passing ¼″ screen	2%
	100%

Weight of dry loose gravel is 89½ lbs. per cu. ft. or 2,410 lbs. per cu. yd.

Weight of dry packed gravel is 97½ lbs. per cu. ft. or 2,630 lbs. per cu. yd.

Voids in loose gravel equal 44½%.

Voids in packed gravel equal 40%.

Specific gravity equals 2.69.

Cement used in these tests was blend cement No. 2,898.

Sand used in these tests was Colorado River sand No. 2,858.

Compression tests

1:2:4 mix (used 8.7% water)

28-day tests	2,315 lbs. per sq. in. (2)
6-months tests	2,750 lbs. per sq. in. (2)

Laboratory Number—2850.

Material—Profit Island mixed gravel 1″ down.

Producer—J. W. Thompson, New Orleans, La.

Character of Aggregate—Consists of more or less rounded pebbles of quartz, chert and flint with considerable sand free from clay or loam.

Mechanical Analysis—Gravel is very well graded, as shown in the following analysis: (Plate II.)

Retained on 1¼″ screen	0%
Passing 1¼″ screen retained on 1″ screen	3%
Passing 1″ screen retained on ¾″ screen	18%
Passing ¾″ screen retained on ½″ screen	22%
Passing ½″ screen retained on ¼″ screen	27%
Gravel 70 per cent of total.	
Passing ¼″ screen retained on ⅛″ screen	12%
Passing ⅛″ screen retained on No. 10 sieve	3%
Passing No. 10 sieve retained on No. 20 sieve	2%
Passing No. 20 sieve retained on No. 28 sieve	2%
Passing No. 28 sieve retained on No. 35 sieve	3%
Passing No. 35 sieve retained on No. 48 sieve	4%
Passing No. 48 sieve retained on No. 65 sieve	2%
Passing No. 65 sieve retained on No. 100 sieve	1%
Passing No. 100 sieve retained on No. 200 sieve	1%
Passing No. 200 sieve	0%
	100%

Sand is 30 per cent of total.

Compression tests

1:4 mix (used 8.8% water) medium consistency

Wt. 147 lbs. per cu. ft. 7.02 sacks cement

28-day tests............................2,845 per sq. in: (2)

1:6 mix (used 9.8% water) wet consistency.

Wt. 144 lbs. per cu. ft. 4.08 sacks cement.

28-day tests............................1,130 lbs. per. sq. in.

The low strength of the 1:6 mix is probably due in part to the fact that the concrete was mixed with an excess of water. It is believed that 1% less water would have produced stronger concrete.

Laboratory Number—2851.

Material—Profit Island screened sand.

Producer—J. W. Thompson, New Orleans, La.

Character of Aggregate—Composed of sharp and rounded grains of quartz with a small proportion of coal dust.

Mechanical Analysis—A medium fine well graded sand, as shown by the following: (Plate IV.)

Retained on No. 10 sieve	1%
Passing No. 10 sieve retained on No. 20 sieve	7%
Passing No. 20 sieve retained on No. 28 sieve	14%
Passing No. 28 sieve retained on No. 35 sieve	29%
Passing No. 35 sieve retained on No. 48 sieve	33%
Passing No. 48 sieve retained on No. 65 sieve	11%
Passing No. 65 sieve retained on No. 100 sieve	4%
Passing No. 100 sieve retained on No. 200 sieve	1%
Passing No. 200 sieve	0%
	100%

Weight of dry loose sand is 97 lbs. per cu. ft. or 2,620 lbs. per cu. yd.

Weight of dry packed sand is 103 lbs. per cu. ft. or 2,780 lbs. per cu. yd.

Voids in loose sand equal 33%.

Voids in packed sand equal 27%.

Specific gravity equals 2.58.

Cement used in these tests was blend cement No. 2,898.

Mortar making qualities of this sand are shown by the following results:

1:3 mix by weight
Tensile strength

	This sand	Standard Ottowa sand
7-day tests	235 lbs. per sq. in. (4)	264 lbs. per sq. in. (4)
28-day tests	310 lbs. per sq. in. (4)	336 lbs. per sq. in. (4)
6-months tests	345 lbs. per sq. in. (4)	366 lbs. per sq. in. (4)

Compression tests made on 2″ cubes

	This sand	Standard Ottowa sand
7-day test	1,592 lbs. per sq. in. (3)	1,592 lbs. per sq. in. (3)
28-day test	2,050 lbs. per sq. in. (3)	2,541 lbs. per sq. in. (3)
6-months test	2,830 lbs. per sq. in. (3)	3,615 lbs. per sq. in. (3)

The relation of the strength of this sand to that of Standard Ottowa sand is as follows:

	Compression strength	Tensile strength
7-day test	100%	89%
28-day test	81%	92%
6-months test	79%	94%

These tests indicate that more cement is necessary with this sand to make a mortar equal in strength with the coarse graded sands.

Laboratory Number—2872.

Material—Pit run gravel.

Producer—McLean Sand and Gravel Co., Carrollton, Dallas Co., Texas.

Character of Aggregate—Consists of rounded and flat pebbles of limestone, fossil, shells and sandstone, many of which contain concretions of calcarious materials. It is free from clay or loam.

Mechanical analysis of this gravel is variable, depending upon the amount of time the material is agitated on the screens as prolonged sieving removes the concretionary material.

The following is approximately correct for quick sieving:

Retained on 1¼″ screen	0%
Passing 1¼″ screen and retained on 1″ screen	1%
Passing 1″ screen and retained on ¾″ screen	6%
Passing ¾″ screen and retained on ½″ screen	12%
Passing ½″ screen and retained on ¼″ screen	24%

Gravel is 43 per cent of the total.

Passing ¼″ screen retained on ⅛″ screen	20%
Passing ⅛″ screen retained on No. 10 sieve	10%
Passing No. 10 sieve retained on No. 20 sieve	7%

Passing No. 20 sieve retained on No. 28 sieve	3%
Passing No. 28 sieve retained on No. 35 sieve	5%
Passing No. 35 sieve retained on No. 48 sieve	8%
Passing No. 48 sieve retained on No. 65 sieve	3%
Passing No. 65 sieve retained on No. 100 sieve	1%
Passing No. 100 sieve retained on No. 200 sieve	0%
Passing No. 200 sieve	0%
	100%

Sand is 57 per cent of the total.

Weight of loose pit-run gravel is 101¾ lbs. per cu. ft. or 2,740 lbs. per cu. yd.

Weight of packed pit-run gravel is 110¾ lbs. per cu. ft. or 2,990 lbs. per cu. yd.

Voids in loose gravel equals 39½%.

Voids in packed gravel equals 34%.

Specific gravity equals 2.70.

Cement used in these tests was blend cement No. 2,898.

Results of compression tests made with this pit-run gravel

1:6 mix (used 8.5% water)

Approx. wt. 146½ lbs. per cu. ft. 5.28 sacks cement

28-day tests..........................1,060 lbs. per sq. in. (2)

1:4 mix (used 8.4% water)

Approx. wt. 147 lbs. per cu. ft. 7.45 sacks cement.

28-day tests..........................2,640 lbs. per sq. in. (2)

Screening the above pit-run gravel through ¼″ mesh sieve to separate the coarse aggregate from the fine. As shown by the mechanical analysis this would give 43% gravel and 57% sand.

The sand

Mechanical analysis of the sand

Retained on ¼″ screen	0%
Passing ¼″ screen and retained on ⅛″ screen	35%
Passing ⅛″ screen and retained on No. 10 sieve	18%
Passing No. 10 sieve and retained on No. 20 sieve	12%
Passing No. 20 sieve and retained on No. 28 sieve	5%
Passing No. 28 sieve and retained on No. 35 sieve	9%
Passing No. 35 sieve and retained on No. 48 sieve	14%
Passing No. 48 sieve and retained on No. 65 sieve	5%
Passing No. 65 sieve and retained on No. 100 sieve	2%
Passing No. 100 sieve and retained on No. 200 sieve	0%
Passing No. 200 sieve	0%
	100%

Weight of loose dry sand is 101½ lbs. per cu. ft. or 2,740 lbs.

per cu. yd.

Weight of packed dry sand is 109¾ lbs. per cu. ft. or 2,960 lbs. per cu. yd.

The gravel

The mechanical analysis of the gravel indicates that it has an excess of the smaller sized pebbles in proportion to the larger size as follows:

Retained on 1¼″ screen	0%
Passing 1¼″ screen retained on 1″ screen	2%
Passing 1″ screen retained on ¾″ screen	14%
Passing ¾″ screen retained on ½″ screen	28%
Passing ½″ screen retained on ¼″ screen	56%
	100%

Weight of dry loose screened gravel is 89¼ lbs. per cu. ft. or 2,410 lbs. per cu. yd.

Weight of dry packed screen gravel is 94½ lbs per cu. ft. or 2,560 lbs. per cu. yd.

Compression tests on concrete in which the proportion of sand to gravel was varied, but the sum of the two aggregates when measured separately was the same and also the amount of cement was the same.

1:2:4 mix (used 9.0% water)
Wt. 149 lbs. per cu. ft. 5.73 sacks cement.
28-day tests..........................2,300 lbs. per sq. in. (4)
1:2.2:3.8 (used 9.0% water)
Wt. 148 lbs. per cu. ft. 5.62 sacks cement
28-day tests..........................2,440 lbs. per sq. in. (2)
1:2.4:3.6 (used 8.7% water)
Wt. 148 lbs. per cu. ft. 5.66 sacks cement)
28-day tests..........................2,160 lbs. per sq. in. (2)

The above indicates that the 1:2.2:3.8 mix gives a slightly better concrete, due probably to the small size of the gravel.

Tension

1:2:4 mix (used 9.0% water)
28-day tests..............................244 lbs. per sq. in.

Abrasion test

1:2:4 mix (used 9.0% water)
28-day test........loss 4.5 per cent by weight in 1,000 revolutions

The surface of the specimen after the run was comparatively smooth, similar to a crushed limestone stone concrete. Everything considered, the surface was quite satisfactory.

The absorption test made on 1:2:4 concrete after it had remained in air indoors for 6 months, but without further drying showed an absorption of 4.75% by weight.

Laboratory Number—2873.

Material—Concrete and building sand.

Producer—McLean Sand and Gravel Co., Carrollton, Dallas County.

Character of Aggregate—Composed of rounded and angular grains of quartz and feldspar with considerable quantity of broken shell.

Mechanical Analysis—Indicates that this is a medium fine sand, somewhat burdened with fine grains. (Plate VII.)

Retained on ⅛″ screen	0%
Passing ⅛″ screen and retained on No. 10 sieve	3%
Passing No. 10 sieve and retained on No. 20 sieve	6%
Passing No. 20 sieve and retained on No. 28 sieve	8%
Passing No. 28 sieve and retained on No. 35 sieve	18%
Passing No. 35 sieve and retained on No. 48 sieve	42%
Passing No. 48 sieve and retained on No. 65 sieve	16%
Passing No. 65 sieve and retained on No. 100 sieve	6%
Passing No. 100 sieve and retained on No. 200 sieve	1%
Passing No. 200 sieve	0%
	100%

Weight of dry loose sand is 91 lbs. per cu. ft. or 2,460 lbs. per cu. yd.

Weight of dry packed sand is 98½ lbs. per cu. ft. or 2,600 lbs. per cu. yd.

Voids in loose sand equal 45%.

Voids in packed sand equal 40½%.

Specific gravity equals 2.64.

Cement used in these tests was blend cement No. 2,898.

Gravel used in these tests was Colorado River gravel No. 2,892.

The mortar making qualities of this sand are shown by the following tests:

Tension test.

1:3 mix by weight (used 11.8% water)

	This sand	Standard Ottowa sand
7-day tests	232 lbs. per sq. in. (4)	247 lbs. per sq. in. (3)
28-day tests	320 lbs. per sq. in. (4)	347 lbs. per sq. in. (3)
6-months test	380 lbs. per sq. in. (4)	347 lbs. per sq. in. (3)

Compressive test

	This sand	Standard Ottowa sand
7-day tests	1,375 lbs. per sq. in. (2)	
28-day tests	2,125 lbs. per sq. in. (3)	2,475 lbs. per sq. in. (2)
6-months test	2,867 lbs. per sq. in. (3)	3,512 lbs. per sq. in. (2)

Comparing the strength of this sand in a mortar with that of the Ottowa sand, the results are as follows:

	Tension tests	Compression tests
7-day tests	94%	
28-day tests	92%	86%
6-months tests	110%	82%

The above tests indicate that this sand is slightly inferior in mortar making qualities to Ottawa sand, and it would require more cement to obtain the same strength.

In order to test this sand as an aggregate for concrete, it was mixed with the well graded Colorado River gravel and tested with the following results:

1:2:4 mix (used 7.74% water)
Wt. 146 lbs. per cu. ft. 5.60 sacks cement

28-day tests	2,270 lbs. per sq. in. (4)
6-months test	2,555 lbs per sq. in. (4)

While these results are satisfactory, a coarse sand would give higher strength using this coarse aggregate.

Laboratory Number—2889.

Material—Broken slag ¼″ to 2″.

Producer—Birmingham Slag Co., Birmingham, Ala. (Slag from Cusley, Ala.)

Character of Aggregate—Consists of sharp angular fragments of a basic blast furnace slag; the greater portion of the stones are hard and dense, although there are a number of porous stones. An occasional stone with iron is found.

Mechanical Analysis—The grading of this material is very good, ash shown by the following analysis: (Plate V.)

Retained on 2″ screen	0%
Passing 2″ screen and retained on 1½″ screen	21%
Passing 1½″ screen and retained on 1¼″ screen	6%
Passing 1¼″ screen and retained on 1″ screen	12%
Passing 1″ screen and retained on ¾″ screen	26%
Passing ¾″ screen and retained on ½″ screen	27%
Passing ½″ screen and retained on ¼″ screen	7%
Passing ¼″ screen	1%
	100%

Weight of loose dry slag is 74½ lbs. per cu. ft. or 2,010 lbs. per cu. yd.

Weight of packed dry slag is 79 lbs. per cu. ft. or 2,140 lbs. per cu. yd.

Voids in loose slag equal 51½%.

Voids in packed slag equal 48½%.

Specific gravity 2.46.

Cement used in these tests was blend cement No. 2,898.

Sands used in these tests were well graded Colorado River sand No. 2,858, Standard Ottowa sand, Crushed slag and Colorado River sand.

Result of compression tests on concrete
1:3:6 mix (used 8.2% water)
Wt. 141 lbs. per cu. ft. 4.6 sacks cement

28-day tests..........................2,100 lbs. per sq. in. (2)
6-months test.........................2,240 lbs. per sq. in. (2)

1:2:4 mix (used medium consistency)
Wt. 144½ lbs. per cu. ft. 6.4 sacks cement

28-day tests..........................2,850 lbs. per sq. in. (2)
6-months tests........................3,550 lbs. per sq. in. (2)

Using Standard Ottowa sand with this crushed slag the following strength was obtained:

1:2:4 mix (used 8.8% water)
Wt. 144½ lbs. per cu. ft. 6.27 sacks cement.

28-day tests..........................2,385 lbs. per sq. in. (2)
6-months tests........................2,630 lbs. per sq. in. (2)

Varying the proportion of sand to coarse aggregate, keeping the sum of these two measured separately equal to 6 and the amount of cement the same, concrete was made and tested with the following results:

28-day tests

Mix	Amount of water used	Compressive Strength lbs. per sq. in.	Weight of cu. ft. of concrete	No. of sacks of cement per cu. yd. of concrete
1:1.6:4.4	....6.8%	2,175 (2)	143½	6.3
1:1.8:4.2	....8.1%	3,020 (2)	144	6.2
1:2:4	....8.4%	2,720 (2)	143½	6.1
1:2.2:3.8	....9.2%	2,645	141	6.0

From the above results it is apparent that the 1:1.8:4.2 mix develops the strongest concrete, but it is also noticeable that the drop in strength in the over sanded concrete is not as great as when it contains too little sand. A characteristic of this slag concrete is that it is rather more difficult to mix well than gravel or stone concrete, but when once mixed it has a much less tendency for the stone to separate from the mortar. For practical purposes it is believed that the 1:2:4 mix would give the most consistent results as it is not so apt to cause pockets as the 1:1.8:4.2.

To determine the value of this slag as a concrete aggregate when screened to smaller size, this slag was passed through a 1″ sq. mesh sieve and that passing this sieve was used in concrete.

The characteristic of this slag under 1″ is as follows:

Weight of dry loose slag under 1″ is 73½ lbs. per cu. ft. or 1,990 lbs. per cu. yd.

Weight of dry packed slag under 1″ is 81½ lbs. per cu. ft. or 2,200 lbs per cu. yd.

Voids in loose slag equal 52.2%.

Voids in packed slag equal 47.0%.

Specific gravity equals 2.46.

Compression tests on concrete made from this slag
1:2:4 mix (used 9.3% water)
Wt. 144 lbs. per cu. ft. 6.25 sacks cement

28-day tests............................1,845 lbs. per sq. in. (2)
6-months tests ....2,480 lbs. per sq. in. (2)

This concrete was mixed to a wet consistency which would have a tendency to lower the strength.

The abrasion test made using the 2″ slag results as follows:

1:2:4 mix (medium consistency)

28-day tests.............lost 2.35% by weight in 1,000 revolutions

The surface of the specimen after this run was comparatively uniform; however, some of the larger slag fragments projected as much as ¼″ from the surrounding surface while the other fragments were worn equal in amount with the mortar and some of them presented porous surfaces. It might be possible that this surface would be well adapted to a bituminous treatment due to the porous nature of the surface.

The absorption tests made on the 1:2:4 concrete after the concrete had remained in air indoors for 6 months showed a gain of 2.91% by weight.

Laboratory Number—2906.

Material—Crushed limestone 1¼″ to ⅛″.

Producer—Mineral Wells Crushed Stone Co., Palo Pinto Co., Mineral Wells, Texas.

Character of Aggregate—Consists of flat and angular fragments of limestone rather uniform in character and containing a small amount of dust.

Mechanical Analysis—Indicates that this is a very well graded aggregate between 1″ and ⅛″, as shown by the following analysis: (Plate V.)

Retained on 1¼″ screen	0%
Passing 1¼″ screen retained on 1″ screen	6%
Passing 1″ screen retained on ¾″ screen	21%
Passing ¾″ screen retained on ½″ screen	31%
Passing ½″ screen retained on ¼″ screen	28%
Passing ¼″ screen retained on ⅛″ screen	11%
Passing ⅛″ screen	3%
	100%

Weight of dry loose stone is 86 lbs. per cu. ft. or 2,320 lbs. per cu. yd.

Weight of dry packed stone is 93½ lbs. per cu ft. or 2,520 lbs. per cu. yd.

Voids in loose stone equal 48%.

Voids in packed stone equal 43½%.

Specific gravity squals 2.66.

Cement used in these tests was blend cement No. 2,898.

Sand used in these tests was Colorado River sand No. 2,858, Colorado River sand below ⅛″, Standard Ottowa sand.

Compression tests using sand No. 2,858 and this stone
1:2:4 mix (used 10.8% water)
Wt. 145½ lbs. per cu. ft. 5.65 sacks cement

28-day tests........2,120 lbs. per sq. in.
6-months tests........2,060 lbs per sq. in.

Using well graded Colorado River sand under ⅛″ with this stone the following results were obtained.

1:2:4 mix (used 9.6% water)
Wt. 145 lbs. per cu. ft. 5.8 sacks cement

28-day tests........2,160 lbs. per sq. in. (2)
6-months tests........2,320 lbs. per sq. in. (3)

Using Standard Ottowa sand with this stone
1:2:4 mix (used 8.6% water)
Wt. 145 lbs. per cu. ft. 5.87 sacks cement.

28-day tests........2,180 lbs. per sq. in. (2)
6-months tests........2,500 lbs. per sq. in. (2)

The tension tests

Using well graded Colorado River sand with this stone

1:2:4 mix (used 10.8% water)

28-day tests............................260 lbs. per sq. in. (1)

Using well graded Colorado River sand under ⅛″ with this stone

28-day tests............................202 lbs. per sq. in. (1)

The abrasion test made on concrete made with well graded Colorado sand and this stone.

1:2:4 mix (used 10.8% water)

28-day tests.............lost 4.37% by weight in 1,000 revolutions

After this test the surface of the ring was very satisfactory, having practically no depressions or swellings. The stone seemed to have worn equal in amount with the mortar.

The absorption test made on this 1:2:4 concrete specimen after it had remained indoors for 6 months was 4.56% by weight.

An abrasion test on concrete made with the Colorado River sand under ⅛″ and this stone resulted as follows:

1:2:4 mix (used 9.6% water)

28-day test.............lost 3.82% by weight in 1,000 revolutions

The surface of this specimen after the test was very satisfactory being uniform, the stone having worn equally in amount with the mortar.

The Absorption test, made on the above 1:2:4 concrete specimen after remaining indoors for 6 months, showed an absorption of 4.31% by weight.

Laboratory Number—2929.

Material—Crushed Limestone 1½″ to ¼″.

Producer—Chico Crushed Stone Co., Chico, Wise Co., Texas.

Character of Aggregate—Consists of fairly hard limestone in flat and angular fragments uniform in quality.

Mechanical Analysis—This seems to be fairly well graded as shown by the following: (Plate V.)

Retained on 2″ screen	0%
Passing 2″ screen and retained on 1½″ screen	1%
Passing 1½″ screen and retained on 1¼″ screen	11%
Passing 1¼″ screen and retained on 1″ screen	18%
Passing 1″ screen and retained on ¾″ screen	20%

Passing ¾″ screen and retained on ½″ screen	36%
Passing ½″ screen and retained on ¼″ screen	12%
Passing ¼″ screen and retained on ⅛″ screen	1%
Passing ⅛″ screen	1%
	100%

Weight of dry loose stone is 84 lbs. per cu. ft. or 2,270 lbs. per cu. yd.

Weight of dry packed stone is 90 lbs per cu. ft. or 2,430 lbs per. cu. yd.

Voids in loose stone equal 49½%.

Voids in packed stone equal 46%.

Specific gravity equals 2.68.

Cement used in these tests was blend cement No. 2,898.

Sand used in these tests was Colorado River sand No. 2,858, Colorado River sand No. 2,943, Standard Ottowa sand.

Cocrete made using Colorado River sand No. 2,858 and this stone gave the following results when tested.

1:2:4 mix (used 8.12% water)
Wt. 148½ lbs. per cu. ft. 6.00 sacks cement)
28-day tests.........................2,670 lbs. per sq. in. (3)
6-months tests.........................3,010 lbs. per sq. in. (2)
Using Ottowa sand and this stone
1:2:4 mix (used 8.5% water)
Wt. 148 lbs. per cu. ft. 6.03 sacks cement
28-day tests.........................2,230 lbs. per sq. in. (2)
6-months tests.........................2,510 lbs. per sq in. (2)

Concrete was made using same amount of cement in each case but varying the proportion of fine to coarse aggregate, keeping the amount of sand and stone measured separately equal to 6.

Colorado River sand was used:

1:1.8:4.2 mix (used 8.8% water)
Wt. 147½ lbs per cu. ft. 5.87 sacks cement
28-day tests.........................2,200 lbs. per sq. in. (2)
1:2:4 mix (used 8.4% water)
Wt. 148½ lbs. per cu. ft. 5.90 sacks cement.
28-day tests.........................2,520 lbs. per sq. in. (4)
6-months tests.........................2,850 lbs. per sq. in. (2)
1:2.2:3.8 mix (used 8.7% water)
Wt. 148½ lbs. per cu. ft. 5.82 sacks cement.
29-day tests.........................2,060 lbs. per sq. in. (2)

From the above results it is evident that the 1:2:4 mix obtained stronger concrete.

The Tension Test made on concrete from Colorado River sand 2858 and this stone showed the following results:

1:2:4 mix (used 8.1% water)

28-day tests............................222 lbs. per sq. in. (1)

The abrasion test on same mix as above

1:2:4 mix (used 8.1% water)

28-day tests............lost 3.12% by weight in 1,000 revolutions

The surface of the specimen after the test was very satisfactory. A few of the softer stones showed a tendency to wear rapidly while a number of the larger stones protrude slightly, however, the surface was as a whole was rather uniform.

The Absorption Test made on the above 1:2:4 mix after remaining indoors for 6 months and without previous drying absorbed 3.4% by weight.

Laboratory Number—2922.

Material—Screened Gravel between ¼″ and 2″.

Producer—Texas Sand Company, Texarkana, Bowie Co., Texas.

Character of Aggregate—Gravel consists of flat and rather angular pebbles of flint, chert, quartz, and some gneiss, clean and comparatively smooth.

Some of the stones show indications of having been broken in a crusher.

Mechanical Analysis—This is not an especially well graded aggregate as it is deficient in pebbles above 1″ in size as shown by the following: (Plate VI.)

Retained on 2″ screen	0%
Passing 2″ screen and retained on 1½″ screen	13%
Passing 1½″ screen and retained on 1¼″ screen	5%
Passing 1¼″ screen and retained on 1″ screen	11%
Passing 1″ screen and retained on ¾″ screen	27%
Passing ¾″ screen and retained on ½″ screen	38%
Passing ½″ screen and retained on ¼″ screen	6%
Passing ¼″ screen	0%
	100%

Weight of dry loose gravel is 92½ lbs per cu. ft. or 2,500 lbs. per cu. yd.

Weight of dry packed gravel is 98¾ lbs. per cu. ft. or 2,660 lbs. per cu. yd.

Voids in loose gravel equal 42½%.

Voids in packed gravel equal 38½%.

Specific gravity 2.58.

Cement used in these tests was blend cement No. 2,898.

Sand used in these tests was Colorado River sand No. 2,943, Texas Sand Cos.' sand No. 2,924, Standard Ottowa sand.

Concrete made using Texas Sand Cos.' sand and this gravel.

1:2:4 mix (used 8.3% water)

Wt. 147 lbs. per cu. ft. 5.50 sacks cement.

28-day tests..............................1,730 lbs. per sq. in.

Concrete made using Standard Ottowa sand and this gravel.

1:2:4 mix (used 7.6% water)

Wt. 151 lbs. per cu. ft. 5.83 sacks cement

33-day test............................2,100 lbs. per sq. in. (2)

Concrete made using Colorado River sand and this gravel.

1:2:4 mix (used 8.4% water)

Wt. 148½ lbs per cu ft. 5.56 sacks cement

28-day tests...........................2,010 lbs. per sq. in. (2)

6-months tests........................2,210 lbs. per sq. in. (3)

A satisfactory concrete is produced using a coarse well graded sand with this aggregate. With better grading of the coarse aggregate, however, a stronger concrete could be produced.

Tension test

1:2:4 mix (used 8.4% water)

28-day test...............................284 lbs. per sq. in. (1)

Abrasion test made on concrete from the Colorado River sand and this gravel.

1:2:4 mix (used 8.4% water)

28-day test.............lost 3.25% by weight in 1,000 revolutions

The surface after the test was very rough, the softer stones wearing equally with the mortar, while the hard flints and quartzites wore but little.

Laboratory Number—2923.

Material—Washed and screened gravel between ⅛″ and ¾″.

Producer—Texas Sand Co., Texarkana, Bowie, Co., Texas.

Character of Aggregate—Gravel is composed of hard, clean pebbles of quartz, chert, and flint most of which have hard smooth surfaces. Several pieces show indications of being crushed.

Mechanical Analysis—This gravel seems to have an excess of pebbles between ½″ and ¼″ as shown by the following: (Plate VI.)

Retained on ¾″ screen	0%
Passing ¾″ screen retained on ½″ screen	11%
Passing ½″ screen retained on ¼″ screen	62%
Passing ¼″ screen retained on ⅛″ screen	26%
Passing ⅛″ screen	1%
	100%

Weight of dry loose gravel is 94½ lbs. per cu. ft. or 2,560 lbs. per cu. yd.

Weight of dry packed gravel is 100½ lbs per cu ft. or 2,720 lbs. per cu. yd.

Voids in loose gravel equal 42%.

Voids in packed gravel equal 38½%.

Specific gravity is 2.62.

Cement used in this test was blend cement No. 2,924.

Sand used in this test was well graded Colorado River sand No. 2,943, Texas Sand Co.s' sand No. 2,924.

Concrete made using Texas Sand Co.s' sand and this gravel.

1:3:6 mix (used 8.2% water)

Wt. 145 lbs. per cu. ft. 3.82 sacks cement.

28-day tests.....1,170 lbs. per sq. in. (2)

6-months tests.....1,190 lbs. per sq. in. (3)

1:2:4 mix (used 8.6% water)

Wt. 144 lbs. per cu. ft. 5.40 sacks cement.

28-day tests.....1,950 lbs. per sq. in. (2)

Concrete made using Colorado River sand and this gravel.

1:2:4 mix (used 8.0% water)

Wt. 147 lbs. per cu. ft. 5.55 sacks cement.

28-day tests.....2,480 lbs. per sq. in. (2)

6-months tests.....3,160 lbs. per sq. in. (3)

Laboratory Number—2924.

Material—Screened sand.

Producer—Texas Sand Co., Texarkana, Bowie Co., Texas.

Character of Aggregate—Composed of clean, sharp grains of quartz, and some feldspar.

Mechanical Analysis—Indicates that this is medium fine graded sand as shown by the following: (Plate VII.)

Retained on ¼″ screen	0%
Passing ¼″ screen and retained on ⅛″ screen	4%
Passing ⅛″ screen and retained on No. 10 sieve	4%
Passing No. 10 sieve and retained on No. 20 sieve	9%

Passing No. 20 sieve and retained on No. 28 sieve	15%
Passing No. 28 sieve and retained on No. 35 sieve	29%
Passing No. 35 sieve and retained on No. 48 sieve	26%
Passing No. 48 sieve and retained on No. 65 sieve	8%
Passing No. 65 sieve and retained on No. 100 sieve	4%
Passing No. 100 sieve and retained on No. 200 sieve	1%
Passing No. 200 sieve	0%
	100%

Weight of loose dry sand is 99½ lbs. per cu. ft. or 2,690 lbs. per cu. yd.

Weight of packed dry sand is 106 lbs. per cu ft. or 2,860 lbs. per cu. yd.

Voids in loose sand equals 40%.

Voids in packed sand equals 36%.

Specific gravity is 2.65.

Sand used in these tests was Standard Ottowa sand, Colorado River sand No. 2,943.

Gravel used in these tests was Colorado River gravel No. 2,892.

Mortar making qualities of this sand are shown by the following tests.

Tensile strength (1:3 mix by weight)

	This sand (used 10% water)	Standard Ottowa sand (used 9.3% water)
7-day test	275 lbs. per sq. in. (4)	268 lbs. per sq. in. (4)
28-day test	459 lbs. per sq. in. (4)	341 lbs. per sq. in. (4)
6-months test	385 lbs. per sq. in. (4)	338 lbs. per sq. in. (4)

Compression strength tests (1:3 mix by weight, made on 2″ cubes)

	This sand (used 10% water)	Standard Ottowa sand (used 9.3% water)
7-day tests	1,812 lbs. per sq. in. (4)	1,625 lbs. per sq. in. (4)
28-day tests	2,968 lbs. per sq. in. (4)	2,550 lbs. per sq. in. (4)
6-months tests	3,318 lbs. per sq. in. (4)	3,668 lbs. per sq. in. (4)

The relation of the strength of the mortar to that of the Ottowa sand is shown by the following:

	Tensile strength	Compressive strength
7-day tests	103%	111%
28-day tests	135%	116%
6-months tests	114%	92%

These tests indicate that this is a satisfactory sand for mortar and is slightly better than Ottowa sand for this purpose.

Comparing this sand with well-graded Colorado River sand when used with a well-graded gravel in concrete the following results were obtained. Using this sand:

1:2:4 mix (used 7.5% water)
Wt. 148 lbs. per cu. ft. 5.50 sacks cement.
28-day tests..........................2,720 lbs. per sq. in. (2)
6-months tests........................3,020 lbs. per sq. in. (3)

Using well graded Colorado River sand No. 2,943
1:2:4 mix (used 7.0% water)
Wt. 150 lbs. per cu. ft. 5.58 sacks cement
28-day tests..........................3,080 lbs. per sq. in. (2)
6-months tests........................3,210 lbs. per sq. in. (3)

Laboratory Number—2930.

Material——Screened Gravel between ¼″ and 1½″.

Producer—White Rock Gravel and Sand Co., Waco, McLennan Co., Texas.

Character of Aggregate—Gravel consists of more or less flat and rounded stone, most of which are limestone with some flint and quartz.

Mechanical Analysis—Indicates that this has an excess of the finer gravel as shown by the following analysis: (Plate VI.)

Retained on 2″ screen	0%
Passing 2″ screen and retained on 1½ screen	8%
Passing 1½″ screen and retained on 1¼″ screen	3%
Passing 1¼″ screen and retained on 1″ screen	14%
Passing 1″ screen and retained on ¾″ screen	14%
Passing ¾″ screen and retained on ½″ screen	25%
Passing ½″ screen and retained on ¼″ screen	30%
Passing ¼″ screen and retained on ⅛″ screen	6%
Passing ⅛″ screen	0%
	100%

Weight of dry loose gravel is 95¾ lbs. per cu. ft. or 2,580 lbs. per cu. yd.

Weight of dry packed gravel is 101 lbs. per cu. ft. or 2,725 lbs. per cu. yd.

Voids in loose gravel equals 40½%.

Voids in packed gravel equals 37½%.

Specific gravity equals 2.59.

Cement used in these tests was blend cement No. 2,898.

Sand used in these tests was Colorado River sand No. 2,943, Standard Ottowa sand.

Compression tests of concrete made from Colorado River sand and this gravel:

1:3:6 mix (used 7.7% water)

Wt. 148 lbs. per cu. ft. 3.90 sacks cement.

28-day tests..........................1,310 lbs. per sq. in. (2)

6-months tests........................1,350 lbs. per sq. in. (2)

1:2:4 mix (used 8.0% water)

Wt. 147½ lbs. per cu. ft. 5.52 sacks cement.

28-day tests..........................2,950 lbs. per sq. in. (2)

6-months tests........................3,140 lbs. per sq. in. (3)

Using Standard Ottowa sand and this gravel

1:2:4 mix (medium consistency)

Wt. 148 lbs. per cu. ft. 5.65 sacks cement.

28-day tests..........................2,353 lbs. per sq. in. (3)

6-months tests........................2,690 lbs. per sq. in. (2)

Abrasion test of concrete made using Colorado River sand and this gravel.

1:2:4 mix (used 8.0% water)

28-day tests...........lost 4.45% by weight in 1,000 revolutions

The specimen after this run was not uniform, the softer limestone pebbles in the gravel wearing equally in amount and in some cases slightly more than the mortar. The hard flints, however, protrude in many cases as much as ½″ above the surrounding surface. Some of the stones have been knocked out of the concrete leaving cavities in the surface.

The absorption test was made on 1:2:4 concrete after it had remained in air indoors for 6 months and showed an increase of 3.62% in weight.

Laboratory Number—2931.

Material—Torpedo Sand.

Producer—White Rock Gravel and Sand Co., Waco, McLennan Co., Texas.

Character of Aggregate—Composed of rounded and angular grains of flint and quartz, and a large proportion of limestone.

Mechanical Analysis—A rather coarse sand as shown by the following: (Plate VII.)

Retained on ¼″ screen	7%
Passing ¼″ screen and retained on ⅛″ screen	24%
Passing ⅛″ screen and retained on No. 10 sieve	18%
Passing No. 10 sieve and retained on No. 20 sieve	14%
Passing No. 20 sieve and retained on No. 28 sieve	7%
Passing No. 28 sieve and retained on No. 35 sieve	7%
Passing No. 35 sieve and retained on No. 48 sieve	7%
Passing No. 48 sieve and retained on No. 65 sieve	5%

Passing No. 65 sieve and retained on No. 100 sieve	4%
Passing No. 100 sieve and retained on No. 200 sieve	3%
Passing No. 200 sieve	4%
	100%

Weight of dry loose sand is 103¼ lbs. per cu. ft. or 2,790 lbs. per cu. yd.

Weight of dry packed sand is 110¼ lbs. per cu. ft. or 2,980 lbs. per cu. yd.

Voids in loose sand equals 36½%.

Voids in packed sand equals 32½%.

Specific gravity equals 2.62.

Cement used in these tests was blend cement No. 2,898.

Gravel used in these tests was well graded Colorado River gravel No. 2,892.

The mortar making qualities of this sand are shown by the following tests.

Tension test
1:3 mix by weight

	This sand	Standard Ottowa sand
7-day tests	343 lbs. per sq. in. (4)	241 lbs. per sq. in. (4)
28-day tests	430 lbs. per sq. in. (4)	316 lbs. per sq. in. (4)
6-months tests	544 lbs. per sq. in. (4)	359 lbs. per sq. in. (4)

Compression cubes

	This sand	Standard Ottowa sand
7-day tests	2,867 lbs. per sq. in. (3)	1,633 lbs. per sq. in. (3)
28-day tests	4,000 lbs. per sq. in. (3)	2,342 lbs. per sq. in. (3)
6-months tests	6,775 lbs. per sq. in. (3)	3,500 lbs. per sq. in. (3)

The relation of the mortar tests using this sand to mortar using Ottowa sand is as follows:

	Tensile strength	Compressive strength
7-day tests	142	176
28-day tests	136	170
6-months tests	151	193

These tests indicate that this is a very good grade of sand for mortar. Using this sand with a well-graded Colorado River gravel in concrete the following results were obtained.

Using this sand and a well-graded Colorado River gravel:

1:2:4 mix (7.6% water)
Wt. 147 lbs. per cu. ft. 5.46 sacks cement.

28-day tests	2,735 lbs. per sq. in. (2)
6-months tests	2,980 lbs. per sq. in. (3)

Laboratory Number—2932.

Material—Building Sand.

Producer—White Rock Gravel and Sand Co., Waco, McLennan Co., Texas.

Character of Aggregate—Sand is composed of angular and rounded grains of quartz, flint, and limestone.

Mechanical Analysis—A well-graded, medium sand as shown by the following: (Plate VII.)

Retained on ¼″ screen	0%
Passing ¼″ screen and retained on ⅛″ screen	0%
Passing ⅛″ screen and retained on No. 10 sieve	4%
Passing No. 10 sieve and retained on No. 20 sieve	11%
Passing No. 20 sieve and retained on No. 28 sieve	12%
Passing No. 28 sieve and retained on No. 35 sieve	17%
Passing No. 35 sieve and retained on No. 48 sieve	19%
Passing No. 48 sieve and retained on No. 65 sieve	15%
Passing No. 65 sieve and retained on No. 100 sieve	10%
Passing No. 100 sieve and retained on No. 200 sieve	7%
Passing No. 200 sieve	5%
	100%

Weight of dry loose sand is 93½ lbs. per cu. ft. or 2,520 lbs. per cu. yd.

Weight of dry packed sand is 100 lbs. per cu. ft. or 2,700 lbs. per cu. yd.

Voids in loose sand equals 43%.

Voids in packed sand equals 39%.

Specific gravity equals 2.63.

Cement used in these tests was blend cement No. 2,898.

Also Ottowa sand.

The mortar making quality of this sand is shown by the following:

Tension test
1:3 mix by weight

	This sand (used 10% water)	Standard Ottowa sand (used 9.3% water)
7-day tests	213 lbs. per sq. in. (4)	245 lbs. per sq. in. (4)
28-day tests	268 lbs. per sq. in. (4)	326 lbs. per sq. in. (4)
6-months tests	324 lbs. per sq. in. (4)	391 lbs. per sq. in. (4)
Compressive cubes		
7-day tests	1,308 lbs. per sq. in. (3)	1,617 lbs. per sq. in. (3)
28-day tests	1,781 lbs. per sq. in.	2,375 lbs. per sq. in.
6-months tests	2,396 lbs. per sq. in.	3,600 lbs. per sq. in.

The relation of the strength of the mortar made from this sand and that made from Ottowa sand is as follows:

	Tensile strength	Compressive strength
7-day tests	87%	81%
28-day tests	82%	75%
6-months tests	83%	66%

Laboratory Number—2774.

Material—Washed Sand.

Producer—Urbana Gravel Co., Houston, Texas, Harris Co.

Character of Aggregate—Composed of rather sharp fragments of quartz and feldspar, free from clay or loam.

Mechanical Analysis—A medium fine sand fairly well graded as shown by the following: (Plate IV.)

Retained on No. 10 sieve	3%
Passing No. 10 sieve and retained on No. 20 sieve	10%
Passing No. 20 sieve and retained on No. 28 sieve	15%
Passing No. 28 sieve and retained on No. 35 sieve	27%
Passing No. 35 sieve and retained on No. 48 sieve	30%
Passing No. 48 sieve and retained on No. 65 sieve	10%
Passing No. 65 sieve and retained on No. 100 sieve	4%
Passing No. 100 sieve and retained on No. 200 sieve	1%
	100%

Weight of dry loose sand is 96½ lbs. per cu. ft. or 2,600 lbs. per cu. yd.

Weight of dry packed sand is 101½ lbs. per cu. ft. or 2,740 lbs. per cu. yd.

Voids in loose sand equals 41½%.

Voids in packed sand equals 38½%.

Specific gravity 2.65.

Cement used in these tests was blend cement No. 2,746.

Sand used in these tests was Standard Ottowa sand.

The mortar making qualities of this sand are shown by the following tests.

Tensile strength (1:3 by weight)

	This sand (used 9.3% water)	Ottowa sand (used 9.3% water)
7-day test	240 lbs. per sq. in. (3)	303 lbs. per sq. in. (3)
28-day test	323 lbs. per sq. in. (3)	377 lbs. per sq. in. (3)
6-months test	349 lbs. per sq. in. (3)	418 lbs. per sq. in. (3)

Compression tests (1:3 by weight) 2″ cubes

	This sand (used 9.3% water)	Ottowa sand (used 9.3% water)
28-day tests	2,806 lbs. per sq. in. (2)	3,300 lbs. per sq. in. (2)
6-months tests	3,200 lbs. per sq. in. (1)	4,250 lbs. per sq. in. (1)

The ratio of strength of mortar made with this sand to that of Ottowa sand:

	Tension	Compression
7-day test	79%	——
28-day tests	86%	85%
6-months test	84%	75%

Laboratory Numbers—2775 and 2860.

Material—Pit-run gravel.

Producer—Urbana Gravel Co., Houston, Harris Co., Texas.

Two small shipments of this gravel were received; no tests were made on the first shipment except the indentifications given here.

Character of Aggregate—Composed of rather sharp pebbles of feldspar and quartz with an abundance of sand of the same character, free from clay or loam.

Mechanical Analysis—A rather poorly graded aggregate with over twice as much sand as coarse gravel. The two shipments check quite closely in grading as shown: (Plate II.)

	First shipment No. 2,775	Second shipment No. 2,860
Retained on 1½″ screen	0%	0%
Passing 1¼″ screen retained on 1″ screen	1%	2%
Passing 1″ screen retained on ¾″ screen	1%	4%
Passing ¾″ screen retained on ½″ screen	4%	6%
Passing ½″ screen retained on ¼″ screen	17%	18%
Coarse aggregate No. 2,775=23 per cent of total.		
Coarse aggregate No. 2,860=30 per cent of total.		
Passing ¼″ screen retained on ⅛″ screen	31%	33%
Passing ⅛″ screen retained on No. 10 sieve	19%	18%
Passing No. 10 sieve retained on No. 20 sieve	14%	10%
Passing No. 20 sieve retained on No. 28 sieve	5%	4%
Passing No. 28 sieve retained on No. 35 sieve	4%	2%
Passing No. 35 sieve retained on No. 48 sieve	2%	1%
Passing No. 48 sieve retained on No. 65 sieve	1%	1%
Passing No. 65 sieve retained on No. 100 sieve	0%	0%
Passing No. 100 sieve	1%	1%
	100%	100%

Sand No. 2,775=77 per cent of total.

Sand No. 2,860=70 per cent of total.

Cement used in these tests is blend cement No. 2,898.

1:4 mix (wet consistency—used 10.3% water)
Approx. wt. 144½ lbs. per cu. ft. Approx. 6.22 sacks cement
28-day test..........................2,035 lbs. per sq. in. (2)
1:6 mix (used 8.2% water)
Approx. 145 lbs. per sq. in. (2) Approx. 5.05 sacks cement
28-day test............................1,635 lbs. per sq. in.

Laboratory Number—2871.

Material—Crushed Trap Rock, (basalt) 1″ to ⅛″.

Producer—Texas Trap Rock Co., San Antonio, Texas, plant at Knippa, Uvalde County, Texas.

Character of Aggregate—Composed of sharp, angular fragments of a very hard, tough basalt free from dust.

Mechanical Analysis—Fairly well graded as shown by the following: (Plate III.)

Retained on 1″ screen................................	0%
Passing 1″ screen and retained on ¾″ screen............	5%
Passing ¾″ screen and retained on ½″ screen............	34%
Passing ½″ screen and retained on ¼″ screen............	42%
Passing ¼″ screen and retained on ⅛″ screen............	14%
Passing ⅛″ screen....................................	5%
	100%

Weight of dry loose stone is 91¼ lbs. per cu. ft. or 2,460 lbs. per cu. yd.

Weight of dry packed stone is 100 lbs. per cu. ft. or 2,700 lbs. per cu. yd.

Voids in loose stone equal 54%.

Voids in packed stone equal 49%.

Specific gravity 3.15.

Cement used in these tests was blend cement No. 2,975.

Sand used in these tests was Colorado River sand No. 2,943, medium sand No. 2,855.

Compression test

Concrete made with this stone and Colorado River sand.

1:2:4 mix (used 9.08% water)
Wt. 156½ lbs. per cu. ft. 6.05 sacks cement
28-day tests..........................2,180 lbs. per sq. in. (2)
6-months test.......................2,500 lbs. per sq. in. (2)

Since the stone was graded to ⅛″ in size, it was thought that perhaps a finer graded sand than the coarse graded Colorado River sand might produce more satisfactory concrete. A finer graded sand somewhat similar to that in the vicinity of San Antonio was used.

Using medium graded sand and this stone:

1:3:6 mix (used 9.51% water)
Wt. 157½ lbs. per cu. ft. 4.34 sacks cement.
28-day test............................1,500 lbs. per sq. in. (2)
6-months test.........................1,400 lbs. per sq. in. (2)

1:2.2:4.4 mix (used 9.70% water)
Wt. 155½ lbs. per cu. ft. 5.55 sacks cement.
28-day tests...........................1,970 lbs. per sq. in. (2)
6-months tests........................2,305 lbs. per sq. in. (2)

1:2:4 mix (used 9.83% water)
Wt. 155½ lbs. per cu. ft. 5.97 sacks cement
28-day tests...........................2,300 lbs. per sq. in. (2)
6-months tests........................2,720 lbs. per sq. in. (2)

1:1½:3 mix (used 9.99% water)
Wt. 156 lbs. per cu. ft. 7.60 sacks cement
28-day tests...........................3,490 lbs. per sq. in. (2)
6-months tests........................4,150 lbs. per sq. in. (2)

Tension test

Using well graded coarse Colorado River sand and this stone.
1:2:4 mix (used 9.08% water)
28-day test...............................280 lbs. per sq. inch.

Using medium graded sand and this stone.
1:2.2:4.4 mix (used 9.70% water)
28-day tests...............................248 lbs. per sq. in.

1:2:4 mix (used 9.83% water)
28-day tests...............................280 lbs. per sq. in.

1:1½:3 mix (used 9.99% water)
28-day tests...............................312 lbs. per sq. in.

Abrasion test

Using a medium graded sand and this stone.
1:2.2:4.4 mix (used 9.70% water)
28-day tests.............lost 2.88% by weight in 1,000 revolutions

The surface of this specimen after the run was comparatively smooth, except for an occasional large stone which protrudes above the surrounding surface.

1:2:4 mix (used 9.83% water)
28-day tests.............lost 3.15% by weight in 1,000 revolutions

The surface of this specimen was worn quite uniform. The individual stones show slight indications of cracking on the surface. A few of the larger stones protrude slightly above the surounding surface.

1:1½:3 mix (used 9.99% water)
28-day test.............lost 2.10% by weight in 1,000 revolutions

The surface of this specimen was worn smooth, and uniform free from depressions and worn equal in amount in all places. A superior surface.